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Beaufort Environmental Monitoring Project 1985-1986 Final Report

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BEAUFORT ENVIRONMENTAL MONITORING PROJECT

1985-1986 FINAL REPORT

Any comments concerning the content of this report should be directed to:

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PREFACE

The restricted objectives of the Beaufort Environmental Monitoring Project should be emphasized. The intent of the project is not to provide recommendations for a definitive research program which would address all the fundamental knowledge gaps that exist in the Beaufort region. The cost of acquiring these data would be very high and may still fail to address the issues which finally emerge as those of regulatory and public concern. The objective of BEMP is to identify and recommend those research and monitoring activities which are considered necessary for the responsible management of a phased development of Beaufort Sea hydrocarbons, through the administration of the relevant legislation administered by INAC. The specific focus and objectives of BEMP should not detract from an overall recognition of our fundamental knowledge gaps in the Beaufort. Encouragement and support should be given to those agencies with responsibilities to conduct research programs which reflect their particular mandate in this region.

David P. Stone
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SUMMARY

The Beaufort Environmental Monitoring Project (BEMP) was initiated in 1983 by Indian and Northern Affairs Canada and Environment Canada and has continued to the present time. Its purpose is to provide the technical basis for the design, operation and evaluation of a comprehensive and defensible environmental research and monitoring program to accompany phased hydrocarbon development in the Beaufort Sea. This document is the report of the activities during the third year of the project and contains recommendations for future environmental studies in relation to bowhead whales.

The primary activities during 1985-86 were (1) a review of relevant studies initiated or completed since December 1984, (2) preparation of project overviews describing the purpose of these investigations and their relationship to existing BEMP hypotheses, (3) the conduct of a workshop on bowhead whales in early February 1986, (4) review of research discussed in two recent conferences on oil-base drilling fluids, (5) revision of Hypothesis 20 dealing with oil-base drilling fluids, and (6) the preparation of this report.

The following is a summary of the conclusions and recommendations that have emerged from previous workshops on each BEMP impact hypothesis. During the present program, only the bowhead whale hypothesis (No. 1) and the oil-base drilling fluids hypothesis (No. 20) were reviewed for validity or modified. Therefore, the conclusions and recommendations for the remaining hypotheses remain unchanged from those presented in the 1984-1985 BEMP report.

HYPOTHESIS NO. 1: Ship traffic, seismic exploration and active offshore structures will cause a reduction in the western Arctic population of bowhead whales.

A relatively large number (N=17) of studies relevant to Hypothesis No. 1 were reviewed and their project summaries distributed before the 1986 BEMP workshop. The conclusion of the 1986 workshop participants was that BEMP Hypothesis No. 1 and its linkages remained valid. As in the previous phases of BEMP, emphasis was placed on the cumulative effect of offshore industrial activities rather than site-specific disturbances. It was recommended that research and monitoring efforts should continue to document the annual patterns of whale distribution in the Canadian Beaufort Sea, and place additional emphasis on investigations of the relationship between bowhead whale distribution and summer food resources. Studies of the behavioural responses of whales to both industrial activity and food resources were also considered useful. In this regard, the development of improved methods for tracking individual whales over the medium and long term (many days, years) was recommended.

HYPOTHESIS NO. 2: Various facilities and activities associated with offshore hydrocarbon development will affect the white whale harvest.

The 1985 workshop participants confirmed the validity of this hypothesis, but concluded that less emphasis should be placed on several of its linkages. In particular, the group expected that delays in ice break-up due to the presence of offshore artificial islands and advanced break-up as a result of icebreaker traffic were both unlikely in view of the present development scenario. Similarly, it was concluded that present levels of ship traffic are

unlikely to prevent white whales from entering the Mackenzie Estuary, although it may cause local and short-term changes in the distribution of whales. Wage employment of hunters in the petroleum industry may change the pattern of hunting, but participants did not expect this to cause a substantial change in the size of the white whale harvest.

Hypotheses dealing with harvesting of resources are being examined in detail in the Mackenzie Environmental Monitoring Program (MEMP). This includes the possible effects of oil and gas development on white whale harvests, which was the subject of a subgroup meeting at the most recent MEMP workshop.

HYPOTHESIS NO. 3: Marine vessel activities, seismic operations, dredging operations, aircraft overflights and active offshore platforms/artificial islands will reduce the size of ringed and bearded seal populations in the Beaufort Sea.

This hypothesis and its linkages were expected to remain valid, but it was concluded during the 1985 workshop that the cumulative effects of all links would probably be inconsequential or too hard to detect (due to natural variability in population levels) at the present level of industrial activity in the Beaufort region. For example, studies conducted by DFO (Western Region) each year since 1981 have shown no correlation between densities of hauled-out seals and proximity to industrial activities. Habitat exclusion resulting from the physical presence of offshore structures and marine vessel traffic were expected to be insignificant at both individual and population levels, while the energetic costs associated with avoidance and diving responses to aircraft overflights would also be inconsequential from a regional perspective.

No specific research or monitoring programs were recommended.

HYPOTHESIS NO. 4: Increased frequency of icebreaker traffic through the landfast ice and through Amundsen Gulf will reduce ringed seal pup production and have subsequent effects on population levels.

After reviewing this hypothesis and its linkages, the 1985 workshop participants concluded that it remained valid in the form presented in the 1983-84 BEMP report. However, a fourth link was added to indicate that reduced ringed seal pup production could result in lower population levels, and the hypothesis was re-worded to reflect this change. It was concluded that the areas of habitat that may be lost due to icebreaker traffic would be small in relation to the available ringed seal breeding habitat in the region. Direct loss of ringed seal pups in icebreaking corridors would occur, but were expected to be a small proportion of total pup production.

During the link-by-link review of this hypothesis, 1985 workshop participants discussed research that would substantially increase understanding of factors affecting ringed seal pup production in Amundsen Gulf and the potential impact on pupping habitat of ice cover destabilization associated with icebreaking. However, it was generally agreed that much of this research would not be possible until some icebreaker traffic occurs in the Gulf. On the other hand, the group recommended continued collection of satellite imagery to provide the basis for future analysis of the relationships between

ice conditions and production and survival of ringed seals, and address the question of destabilization of the ice cover due to icebreaker traffic.

HYPOTHESIS NO. 5: Icebreaker traffic in the transition (shear) zone will reduce bearded seal pup production.

Although no research relevant to this hypothesis has been conducted since 1984, the 1985 workshop subgroup concluded that it remained valid. The group concluded that a research program could be designed to determine the direct effects of icebreaker traffic on seal vocalizations, but since these studies are unlikely to provide information on how decreased vocalization rates may affect mating behaviour or success, they were considered a low priority in the context of the present hypothesis.

Icebreaker traffic in the transition zone will result in mortality of some bearded seal pups, but losses were expected to be extremely small given the present development scenario. Because it would be difficult to detect changes in pup production following the anticipated small losses, no research or monitoring was recommended to address this aspect of Hypothesis No. 5.

No research relevant to this hypothesis was conducted in 1985-86.

HYPOTHESIS NO. 6: Icebreaker traffic in Amundsen Gulf will affect ringed seal and polar bear populations.

The complexity and testability of this hypothesis were a subject of much discussion during the 1985 workshop because it encompasses all the trophic levels in the marine ecosystem of Amundsen Gulf, and involves processes and biological resources that are characterized by a high degree of natural variability. Nevertheless, the hypothesis itself was expected to remain valid. Several ongoing research projects by DFO will provide information relevant to one or more of its linkages. Studies of ringed seals (Arctic Biological Station) and polar bears (Canadian Wildlife Service) were expected to result in data that will be useful in evaluation of upper links in the hypothesis. Many of the uncertainties associated with Hypothesis No. 6 related to the limited information on Arctic cod and its trophic relationships in the region.

Other than continuation of ongoing research programs related to this hypothesis, no research or monitoring programs directed explicitly at any of its linkages were recommended in 1985. However, the workshop subgroup identified two general concerns regarding the availability of fundamental data on ice cover in the Beaufort Sea and Amundsen Gulf. Firstly, the present limited communication between life science specialists and ice scientists was believed to be hampering existing research programs. It was recommended that increased cross-disciplinary contact between these groups be encouraged. The second concern was that no effort is presently being directed at assuring the continued availability of low cost ice data such as daily, full resolution NOAA satellite imagery. The group concluded that attempts should be made to ensure that sea ice data collection and analysis are continued to the extent required for the optimal interpretation of the results of biological studies. Summary catalogs of available imagery should be prepared for future access by researchers in the Beaufort region.

HYPOTHESIS NO. 7: The presence of active facilities will result in increased polar bear mortality.

After examination of this hypothesis and its linkages, the 1985 working group concluded that both remained valid. Personnel on drill rigs continue to report the coincidence of bears with offshore structures but few bears are killed. Only one problem bear was destroyed in the Beaufort region during 1984; two bears were destroyed in 1985. Considerable progress has been made in the development of methods for detecting and deterring bears. Recent research on detection techniques has focused on microwave and infra-red instruments, while polar bear deterrant studies have involved further evaluation of the effectiveness of the rubber bullet gun, plastic slugs fired from a shotgun, and sound-producing devices.

The participants in the 1985 workshop re-confirmed support for research on polar bear detection and deterrent techniques, as well as the possible use of certain detection instrumentation for the censusing of marine mammals. There was considerable concern regarding the unknown status of the Alaskan subsistence polar bear harvest, which is focused on females with cubs. In the absence of appropriate data on this harvest, it was emphasized that declining numbers of polar bears in the Beaufort region might be incorrectly attributed to either the Canadian harvest or industrial impacts.

HYPOTHESIS NO. 8: Offshore development activities will reduce the harvest of polar bears.

Participants in the 1984 workshop concluded that this hypothesis was unlikely and, therefore, did not warrant any specific research or monitoring. The 1985 workshop group agreed with this overall conclusion and recommendation at the current level of industrial activity in the Beaufort Sea. During the period when polar bears are harvested, icebreaker tracks would quickly refreeze and are unlikely to impede hunter travel over the landfast ice. However, as in the previous hypothesis, the group concluded that any future monitoring efforts would be hampered by the lack of data on the Alaskan subsistence harvest of polar bears. Participants indicated that without adequate information on this hunt, it will not be possible to determine the factors responsible for any future declines in total numbers of polar bears.

HYPOTHESIS NO. 9: Chronic/episodic oil spills resulting from normal hydrocarbon development activities within and adjacent to the marine environment will result in localized mortality of polar bears.

Information presented by petroleum industry representatives during the 1985 workshop indicated that chronic oil spills associated with exploration activities are both infrequent and relatively small. Nevertheless, research conducted with captive polar bears has shown that this species is extremely sensitive to oil contact and/or ingestion. As a result, the present group endorsed and encouraged the publication and implementation of an "Action Plan for Protection of Polar Bears in the Event of a Major Oil Spill", which has been prepared by federal, territorial and provincial polar bear biologists. This report is scheduled to be submitted to the Polar Bear Advisory Committee in June 1986.

Workshop participants in 1985 also recommended development of a plan that would allow effects monitoring of "spills of opportunity". Such a plan should (1) identify a scientific team to respond to spills, and (2) provide a description of what and how monitoring should be initiated (including associated research) in the event of a spill. The group concluded that revisions to this or other plans may be necessary at a later date to address opportunistic research/monitoring, as well as to consider other species of marine mammals. The 1985 workshop participants considered it important that the Action Plan be reviewed by the oil industry as soon as possible to allow proper integration of its contents into present oil spill contingency plans for the Beaufort region. To date this has not occurred.

A research program to determine the behavioural responses of polar bears to oil-covered waters and oil-contaminated prey was discussed during the 1985 workshop. However, it was concluded that this research would encounter considerable opposition and, therefore, was considered untenable at present.

HYPOTHESIS NO. 10: Chronic (episodic) oil spills resulting from normal hydrocarbon development activities within and adjacent to the marine environment will result in local mortality of certain species of birds.

This hypothesis was combined with Hypothesis No. 11 during the 1985 workshop, because it was concluded that the latter was simply a specialized case of a more general hypothesis related to the effects of chronic oil spills on bird populations. Several of the original linkages in Hypothesis No. 11 were considered invalid or improbable and, therefore, were removed during this consolidation.

Much of the discussion in the 1985 workshop focused on the need to monitor and record the incidence of oiled birds (or other wildlife) to document the effects of incidental oil spills. Consensus was not reached on this question, largely because there have been no reports of bird mortality to date following chronic spills in the region and this is not an area of significant concern in other oil producing regions of the world. It was concluded that oil spill reports should continue to include any observations of oiled wildlife. With possible future hydrocarbon production, chronic oil spills may increase in frequency and volume from present levels, and this may then justify implementation of a systematic monitoring program.

HYPOTHESIS NO. 11: Oil slicks in open water areas around offshore structures during normal periods of ice cover will cause increased mortality of eiders and diving ducks.

This hypothesis was combined with Hypothesis No. 10 during the 1985 workshop, and no longer exists in its original form.

HYPOTHESIS NO. 12: Frequent low altitude aircraft flights over staging brant will cause increased overwinter mortality.

During the 1984 BEMP workshop, it was concluded that this hypothesis was invalid. Consequently, it was not re-evaluated in 1985.

HYPOTHESIS NO. 13: Shorebases and shallow-water production facilities will release hydrocarbons and heavy metals at sufficient levels such that fish harvest will be reduced through tainting and heavy metal accumulations.

In 1985, the consensus of the working group was that Hypothesis No. 13 remained valid and an area of relatively high profile with respect to BEMP, particularly those links leading from chronic hydrocarbon exposure to the tainting of fish. Federal government agencies are presently collecting data on hydrocarbon and trace metal levels in sediments and biota in several areas of the Beaufort Sea. The group recommended comparative analyses of the data from these studies to identify any areas where elevated body burdens of trace metals and hydrocarbons in benthic fauna or fish can be correlated with contamination of sediments.

As in the 1984 workshop, it was recommended in 1985 that a program of time series measurements of hydrocarbons in fish be initiated in Tuktoyaktuk Harbour. The possible routine measurement of mixed-function oxidise (MFO) activity in fish was also examined and concluded to be worth future consideration as a potential component of the recommended monitoring program. No specific effects monitoring programs for heavy metal uptake by fish or other biota were recommended. Participants expected that potential concerns related to heavy metal contamination could be adequately addressed through standardized compliance monitoring of waste discharges.

In 1985 a study to detect effects of potential contaminants in Tuktoyaktuk Harbour was initiated by Environment Canada. The first year of the three-year study is for the design of a monitoring approach and initial testing of techniques.

HYPOTHESIS NO. 14: Nearshore structures will disrupt the nearshore band of brackish water and reduce the broad whitefish population.

During the 1985 workshop, two new links were added to this hypothesis to include consideration of the effects of changes in the slope of the sea bottom on broad whitefish. Studies of causeways in Prudhoe Bay indicate that nearshore structures could cause changes in temperature and salinity regimes that subsequently affect the distribution of broad whitefish in the southeastern Beaufort Sea. However, it is not known if such changes in distribution would have significant implications to broad whitefish populations or their harvest. A number of research programs that are being conducted by the Freshwater Institute (DFO) are relevant to one or more of the linkages in this hypothesis.

A brief, broadly-based study to summarize available information on the range of coastal oceanographic conditions present in the Beaufort Sea was recommended in 1985, even though causeways are not presently part of the regional hydrocarbon development scenario. Such research would aid in evaluation of the potential for causeways to disrupt nearshore temperature/salinity patterns in different subareas and the vulnerability of broad whitefish in each subarea. The group also emphasized the need to initiate research on nearshore oceanography and fish distribution and movements as soon as possible if causeways are eventually envisioned.

HYPOTHESIS NO. 15: Nearshore structures will disrupt the nearshore band of brackish water and will reduce the Alaskan population of Arctic cisco.

As in 1984, the 1985 workshop group concluded that the links in Hypothesis No. 15 could not be proved or disproved on the basis of existing information, and there was no evidence for rejection of the overall hypothesis. The results of recent investigations conducted near the Prudhoe Bay causeway strengthened the overall hypothesis, while a DFO study on the Yukon coast is expected to provide information relevant to one of its links. The continued monitoring of the Alaskan commercial Arctic cisco fishery in the Colville River will also provide evidence on whether or not Arctic cisco migrations are being affected by the existing causeway in Prudhoe Bay. However, the group identified the lack of temperature/salinity data within a few hundred metres of the coastline as a particularly serious information deficiency and, therefore, recommended increased emphasis on collection of temperature, salinity and other physical oceanographic data during biological field research in this region.

As in Hypothesis No. 14, participants in the 1985 workshop discussed a research program to assess the vulnerability of different areas from the Mackenzie Delta to the U.S./Canadian border to disruptions in current, temperature and salinity regimes from causeway construction. It was concluded that the potential for disruption of nearshore T/S patterns is probably greater along the Yukon coast than along the Tuktoyaktuk Peninsula. As a result, a low level study to examine regional differences in vulnerability of different areas to shoreline modifications was recommended.

HYPOTHESIS NO. 16: The construction of shorebases and development of shallow-water production fields will result in a decrease in the populations of Arctic cisco and broad whitefish.

The major rationale for re-evaluation of this hypothesis in the 1985 workshop was a potential change in development scenario involving the siting of a production facility (i.e., ADGO) in an area where the water depth is less than 5 m. Although participants concluded that the hypothesis was valid, significant impacts of production waste discharges from this field were considered extremely unlikely due to the small volumes of effluent expected. However, the hypothesis and possible research/monitoring needs should be re-examined in the future if anticipated volumes of produced water increase substantially from present estimates.

HYPOTHESIS NO. 17: Water intakes will reduce populations of broad whitefish and Arctic cisco.

In both the 1984 and 1985 workshops, this hypothesis was considered extremely unlikely because the waterflood requirements in Canadian nearshore fields were expected to be small compared to those of the Alaskan fields. Nevertheless, the group did recommend review of the U.S. monitoring program results to determine if this hypothesis should be re-evaluated at some future date.

HYPOTHESIS NO. 18: Air emissions resulting from the operation of aircraft, marine vessels, drill rigs, offshore platforms and shorebases will adversely affect air quality.

During the first workshop, it was concluded that this hypothesis was unlikely given the anticipated quantities of air emissions associated with offshore hydrocarbon development in the Beaufort region. Consequently, it was not re-examined during 1985 or 1986.

HYPOTHESIS NO. 19: Dredging and deposition of dredge spoil will reduce the bearded seal population.

Since Hypothesis No. 19 was prepared outside of the formal workshops during Phase 1 of BEMP, the 1985 workshop was the first time that the linkages had been subjected to critical review. Although few recent or ongoing research programs in the Beaufort region were directly relevant to this hypothesis, it was noted that a great deal of information on the environmental effects of dredging is available for other geographic areas in the world.

Following a review of the validity of each linkage, 1985 workshop participants concluded that, on the basis of worldwide experience regarding the effects of dredging operations and the anticipated intensity and locations of dredging required in the Beaufort Sea, this hypothesis was unlikely and did not justify testing. However, it was stated that bioaccumulation of some contaminants (particularly heavy metals) could occur in the livers of individual bearded seals if they fed in areas of active dredging for extended periods. Consequently, measurement of heavy metal concentrations in bearded seal livers was recommended on an opportunistic basis because of the possible link to human health.

HYPOTHESIS NO. 20: The discharge of cuttings contaminated with oil-base drilling muds during hydrocarbon exploration and production will reduce populations of fish, birds and marine mammals, and will also decrease the harvest of these resources due to hydrocarbon accumulation in tissues.

This hypothesis was developed and evaluated during the 1985 workshop because of a change in the development scenario that may involve use of oil-base drilling muds for certain applications. For the purpose of the group's discussion, it was assumed that cuttings contaminated with oil-base mud may be discharged in shallow nearshore waters used by anadromous fish species. Following a link-by-link review of the hypothesis, it was concluded that tainting of anadromous fish could occur as a result of the ingestion of benthic epifauna that accumulate hydrocarbons associated with cuttings piles on the sea floor. Although this aspect of Hypothesis No. 20 was considered both valid and testable from a site-specific perspective, it was expected that effects of cuttings disposal on the regional populations of Arctic cisco, broad whitefish and lake whitefish would be insignificant.

This hypothesis was revised during the present program to include possible effects on birds and marine mammals. Detailed examination of the revised hypothesis will occur during future BEMP workshops and associated reviews of ongoing research programs.

RÉSUMÉ

Le projet de surveillance environnementale de la mer de Beaufort (PSEB) a été entrepris en 1983 par le ministère des Affaires indiennes et du Nord canadien et par le ministère de l'Environnement. Ce projet doit permettre d'obtenir les données techniques de base nécessaires pour concevoir, exécuter et évaluer un programme de recherche et de surveillance environnementales qui soit à la fois complet et justifiable. Ce programme mis en oeuvre parallèlement à l'exploitation graduelle des hydrocarbures dans la mer de Beaufort termine sa troisième année. Ce rapport fait état des activités de recherche entreprises durant cette année et renferme des recommandations quant aux études environnementales qui pourraient être entreprises à l'avenir.

INTRODUCTION

During 1983, Indian and Northern Affairs Canada and Environment Canada initiated the Beaufort Environmental Monitoring Project (BEMP). The program is to provide the technical basis for the design, operation and evaluation of a comprehensive and defensible environmental research and monitoring program to accompany hydrocarbon development in the Beaufort Sea relative to the regulatory responsibilities of the sponsoring departments. BEMP was considered necessary because of: (1) environmental concerns regarding this development; (2) uncertainties associated with Environmental Impact Assessment (EIA); and (3) the need for a research and monitoring plan that is fully integrated with ongoing exploration and future production activities.

Results of the first BEMP program are reported in Indian and Northern Affairs Canada and Environment Canada (1984). The second BEMP program proceeded in 1984-1985 and is documented in Indian and Northern Affairs and Environment Canada (1985). The present report describes BEMP activities in 1985-1986. It records, in detail, activities that occurred during the third year of BEMP, and also summarizes conclusions and recommendations of the BEMP program since its inception.

It is important to recognize that the annual BEMP programs are not intended to be repetitive, going through the same processes year after year. BEMP is designed to be adaptive, in that the program changes as new scientific understanding is achieved, development plans change or priorities are modified. The first year of the program was informative in that the study approach and philosophy were developed and put into action. The second year re-examined all issues identified in the first year's program and introduced new or modified issues that resulted from changing development plans. This third year of BEMP was a reduced effort since it was apparent that all issues need not be intensively examined on an annual basis.

Monitoring and Research

For BEMP, **monitoring is defined as a test of an impact hypothesis designed to (a) measure environmental impacts; and (b) analyse cause-effect relationships.** As such, monitoring is a scientific process designed to test specific hypotheses linking sources of environmental impact (actions) to their expression in the environment. On the other hand, **research is a test of a process hypothesis, required to increase fundamental knowledge regarding the physical and biological environment.**

Complementary Programs

In 1985, a comparable program was initiated to determine research and monitoring priorities related to possible effects of hydrocarbon development and transportation in the Mackenzie Delta and Valley regions. This program is referred to as the Mackenzie Environmental Monitoring Project or MEMP. While BEMP deals with the marine aspects of hydrocarbon development, MEMP is concerned primarily with the terrestrial components of the region including the Mackenzie Delta and the lower Mackenzie Valley. The two programs are, however, closely linked and complementary. To avoid duplication, the BEMP steering committee decided to address issues related to resource harvesting as part of MEMP, while providing technical and financial assistance to allow all

aspects (onshore and offshore) of resource harvesting to be evaluated. BEMP, therefore, remains primarily oriented toward offshore biological issues, whereas MEMP, with a strong representation of native harvesters, devotes considerable effort to defining the relationships between hydrocarbon development and resource harvesting. This includes the harvest of marine animals such as white whales.Moreover, some mammals can be considered Valued Ecosystem Components in both terrestrial and marine environments. For example, Arctic fox spend a considerable portion of the year foraging on the sea ice, but are only considered within MEMP to minimize duplication of effort between the two programs.

OVERVIEW OF YEAR I: 1983-1984

The project employed the overall approach of adaptive Environmental Assessment and Management described by Holling (1978). A brief summary of the first year of BEMP is provided below, while full details are given in the 1983-1984 Final Report for the project (Indian and Northern Affairs Canada and Environment Canada 1984).

First Workshop

A number of tasks were completed at the first workshop (16-20 May 1983, Victoria, B.C.) including determination of the project boundaries, selection of Valued Ecosystem Components (VECs), description of the hydrocarbon development scenario, and development of a simple simulation model.

The geographical extent of the project was defined as extending from Amundsen Gulf to a seaward extention of the Alaska-Yukon border (Figure 1). A line projected westward from the northwestern tip of Banks Island was used to delineate the northern boundary, while the landward extent of the study area was limited to 2 km inland within the Mackenzie Delta, and to the level of storm surges elsewhere. The temporal horizon of the development scenario was set at 30 years.

VECs were defined as **environmental resources that: (1) are important to local human populations; or (2) have national or international profiles; and (3) if altered from their existing status, will be important in evaluating the impacts of development and in focusing management or regulatory policy.** The identification of VECs focused the discussion of research and monitoring programs on those resources and supporting physical processes that are of greatest concern with respect to hydrocarbon development in the region. The final Valued Ecosystem Components determined by workshop participants were air quality and the population and harvest of:

- .bowhead whale
- .white whale
- .ringed seal
- .bearded seal
- .polar bear
- .common eider
- .king eider
- .diving ducks (oldsquaw, scoters, scaups)
- .thick-billed murre
- .brant
- .lake whitefish
- .broad whitefish
- .least cisco
- .Arctic cisco
- .Arctic char

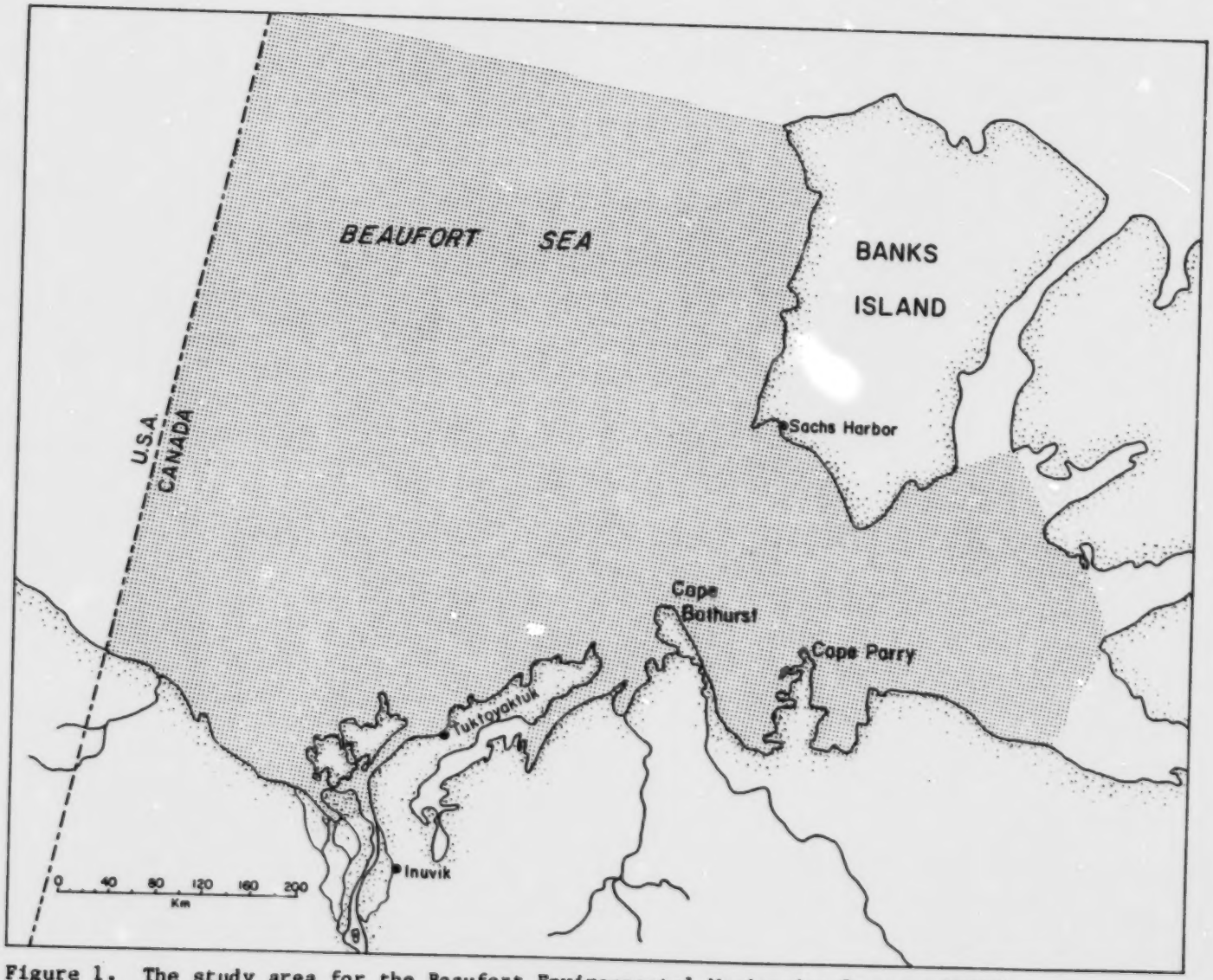

Figure 1. The study area for the Beaufort Environmental Monitoring Program (BEMP).

A development scenario involving four offshore production islands, a peak production rate of 100,000 bbls d^{-1} and transport of crude oil out of the region in two icebreaking tankers was eventually selected as the most suitable scenario for BEMP (based on information provided by workshop participants from the petroleum industry). It was assumed that production facilities would not be located in waters less than 5 m deep, and that formation cuttings contaminated with oil-base drilling muds would not be discharged to the marine environment.

The simulation model was not developed or utilized for predictive purposes. Its value to the project was its actual construction, which required workshop participants with specialized disciplines to think in interdisciplinary and quantitative terms about the possible interactions between the development scenario and the environment. These relationships were represented by a network of linkages, interconnecting detailed components of the development scenario, and components of the biological, physical and chemical environment with the identified Valued Ecosystem Components.

At a number of subsequent technical meetings, impact hypotheses were developed utilizing the linkages established between industrial activities and VECs. Some of these hypotheses involved only one or two linkages, while others involved complex food web interactions with several linkages. During the technical meetings, linkages in the model were further refined and the number of impact hypotheses reduced to those considered most plausible given the existing development scenario. However, it is emphasized that the 21 hypotheses eventually selected for evaluation at the second workshop encompass a considerably larger number of perceived concerns associated with Beaufort hydrocarbon development by virtue of the multiple linkages involved in most of these hypotheses.

Second Workshop

The second BEMP workshop involved 47 participants and was held in Victoria, B.C. from 28 November to 2 December 1983. Each impact hypothesis was reviewed and modifications to the hypothesis structure and associated linkages were completed. At this time, one additional hypothesis related to dredging was added. Each hypothesis was then critically evaluated by a working group, and a monitoring program was proposed in those cases where the hypothesis was considered valid and important to test. The working groups differed from the discipline-specific modelling subgroups of the first workshop, and were restructured daily to include a cross-section of expertise relevant to all aspects of the hypothesis under discussion.

Five steps were involved in the evaluation of each impact hypothesis:

1. **Clarification of the Hypothesis:**

   This step involved reaching a consensus within the working group regarding the structure of the hypothesis and, if necessary, restatement of the hypothesis or its associated linkages.

2. Documentation of Existing Knowledge:

The following information was documented for each of the linkages comprising a hypothesis:

- evidence for and against;
- uncertainties; and
- other potentially useful information.

3. Conclusions:

On the basis of discussions in the above step, the working group then arrived at one of four conclusions for a given impact hypothesis:

- it was extremely unlikely and would not justify testing;
- it was possible, but too difficult to detect;
- more information was required before a monitoring plan could be designed; or
- it should be tested with a detailed monitoring plan.

4. Monitoring and Research:

If the subgroup agreed that one of the latter two conclusions was true, a discussion of recommended research and/or monitoring was initiated. Research generally fell into one of three categories: that necessary to (1) provide the information required to determine if monitoring is justifiable, (2) allow design of a monitoring program, and (3) aid in interpretation of the results of a monitoring program.

5. Documentation:

The discussion, conclusions and recommendations of the working groups were summarized by a "recorder" assigned to each group. These summaries were, in most cases, word-processed at the end of each day, circulated to the working group participants for review and comment, and eventually formed the framework for the 1983-84 BEMP Final Report (Indian and Northern Affairs Canada and Environment Canada 1984).

Conclusions and Recommendations

A total of 19 impact hypotheses were evaluated in detail during the first year of the Beaufort Environmental Monitoring Project, while an additional three hypotheses related to resource harvesting were posed but not discussed in the 1983-84 BEMP report. At that time, monitoring programs were recommended in relation to six of the 19 hypotheses, while monitoring was expected to be necessary for four additional hypotheses depending on the results of recommended research or possible changes in the hydrocarbon development scenario. Recommendations for continuation of ongoing research programs or initiation of new research were also provided for six of the 19 hypotheses evaluated.

OVERVIEW OF YEAR II: 1984-1985

BEMP activities during 1984-85 consisted of: (1) a review of 1984-85 research and monitoring projects, (2) determination of the potential

relationship of each of these programs to the existing BEMP hypotheses and their associated linkages, (3) preparation of brief project overviews for each program that may provide information relevant to the existing hypotheses and VECs, (4) planning and invitation of participants for the annual BEMP workshop, (5) conduct of the 1984-85 BEMP workshop, and (6) preparation of a final report.

Changes in the Hydrocarbon Development Scenario

Two significant changes to the development scenario were:

1. In the initial year of BEMP, it was assumed that offshore production facilities would not be located in waters less than 5 m deep. This assumption is no longer valid because of current interest in production from the ADGO field, which is located in the nearshore zone where water depths range from 2-3 m. Although the petroleum industry presently has no plans to incorporate nearshore structures such as jetties or causeways with this or other shallow-water production facilities, it was assumed for the 1985 workshop that such structures could be proposed in the future.

2. The use of oil-base drilling fluids became part of the development plan because of their inclusion in drilling applications in the Beaufort Sea. Therefore, it was assumed that cuttings contaminated with oil may be discharged as part of routine operations in the region.

In addition, the development scenario originally utilized involved an initial transportation mode of two ice-breaking tankers. In 1984-85, there was a revival of interest in a Mackenzie Valley pipeline as a probable first step in a phased development of Beaufort Sea oil. Nevertheless, a combined tanker/ pipeline scenario remains a distinct possibility. Additional hypotheses may be necessary in the future to address issues associated with the sub-sea pipelines associated with this scenario.

New Hypotheses and VECs

Due to the above changes in the development scenario involving the possible use of oil-base drilling fluids, a new hypothesis related to the potential impacts of oil-contaminated cuttings discharge on anadromous species of fishes was developed and evaluated at the February 1985 workshop.

A proposal to add the coastal zone to the list of VECs was also received at the workshop. It was evaluated and rejected by the BEMP Management Committee.

Workshop

At the February 1985 workshop, participants were assigned to interdisciplinary subgroups to review the hypotheses that emerged from Phase I of BEMP. The following steps were followed during the review of each hypotheses:

1. The origin, links, past conclusions and recommendations for research and monitoring related to the hypothesis were reviewed.

2. The results of recent studies (both completed and ongoing) that provide information relevant to each hypothesis link were reviewed.

3. Each link was evaluated in the context of this new information to assess:

   (a) changes in interpretation;

   (b) implications to future research and monitoring; and

   (c) implications to the overall hypothesis, including the alteration, addition or consolidation of links.

4. The overall hypothesis was evaluated in terms of the need for future research and monitoring.

5. Opportunities for integration and coordination of studies to maximize collection of information relevant to the hypothesis and its associated linkages were discussed.

Each working group addressing a specific hypothesis included a workshop facilitator and a designated recorder. As in the case of previous BEMP workshops, discussions of the working groups were usually word-processed at the conclusion of each day and provided to participants for review during the course of the workshop. Not all of the 19 hypotheses described in the 1983-84 BEMP report were reviewed during the 1985 workshop. The original hypotheses dealing with the effects of aircraft on staging brant (Hypothesis No. 12) and the effects of various emissions associated with offshore industry operations on air quality (Hypothesis No. 18) were not re-examined. This was because the former hypothesis was concluded to be invalid during the previous BEMP workshop, while the latter hypothesis was considered unlikely given the projected air emissions.

Conclusions and Recommendations

As a result of detailed examination of 17 hypotheses, seven research programs and four monitoring programs were recommended. Two of the four monitoring programs were to be performed on an opportunistic basis.

During the second year of the program, it became apparent that all hypotheses do not require detailed examination on an annual basis and that future programs would likely be focused on a few key potential impact hypotheses. Re-examination of all the hypotheses may be necessary every 4-5 years. During this phase of the project, a procedure was developed for the introduction of VECs and new impact hypotheses. New VECs can only be proposed by submission of a statement of specific rationale and supporting evidence to the BEMP Management Committee. If the committee agrees that the proposed VEC meets the criteria identified earlier, impact hypotheses would be developed and evaluated at the following BEMP workshop. New hypotheses involving existing VECs can also be proposed prior to or at the beginning of a workshop.

OVERVIEW OF YEAR III: 1985-1986

Objectives

The objectives for the third consecutive year of BEMP were restricted to the following:

1. Update of the industrial development scenario;

2. Review of 1985-86 investigations in relation to all BEMP hypotheses;

3. Examine two hypotheses in brief but intensive workshops: Hypothesis 1, Bowhead Whales; Hypothesis 20, Oil-base Drilling Muds; and

4. Continue to provide a focus for review and evaluation of environmental/development issues in the Beaufort Sea and important liaison among industry, government and the scientific community.

Changes in the Hydrocarbon Development Scenario

There have been no major changes in the hydrocarbon development scenario in terms of methods of exploration and possible production. The use of oil-base drilling muds in the Beaufort Sea was introduced in 1984-1985 and it remains a focus of attention in 1985-1986.

Since the initiation of BEMP, there appears to be de-emphasis of future marine transportation of hydrocarbon by tankers and more interest in pipelines through the Mackenzie Valley. This is evident as a result of the following activities:

1. recent completion of the oil pipeline from Norman Wells, N.W.T. to Zama Lake, Alberta;

2. submission of an application from Polar Gas to construct a gas pipeline through the Mackenzie Valley; and

3. consideration of a small- or medium-diameter oil pipeline from the Mackenzie Delta to Norman Wells or Zama Lake.

However, the future transportation plan will depend on a range of economic and engineering considerations, and ice-breaking oil tankers remain a possibility.

It is noteworthy that completion of the oil pipeline from Norman Wells has increased the pace of exploration in adjacent regions. Development of the initial transportation system(s) for Beaufort Sea oil will no doubt have a similar effect. The present low world price of crude oil could slow development of hydrocarbon resources in the Beaufort Sea in the short term, but production within the 30-year time frame of the current development scenario still appears to be a reasonable expectation.

Current Research

Over 60 research programs were reviewed as part of the project this year and their relevance to BEMP hypotheses is discussed in PART 3 of this report.

The largest number (N=17) of the research programs were related to bowhead whales, one of the resources of greatest environmental concern with respect to Beaufort Sea hydrocarbon development. Ten programs involved white whales and seven were directly related to ringed or bearded seals. Polar bears were the subject of nine research programs and 10 concerned fish (Arctic cisco and broad whitefish). Only one investigation was directed at birds. A substantial number (N=7) of programs were pertinent to the oil-base drilling muds hypothesis, and most of these focused on hydrocarbon chemistry and biological effects.

Summaries of investigation that were reviewed during this year of BEMP are provided in PART 3. Although these summaries are presented with the hypotheses to which they are most relevant, a substantial number of studies are relevant to more than one hypothesis, and cross-referencing has been used extensively among the various project summaries.

Bowhead Whale Workshop

The bowhead whale workshop was held 11-12 February 1986 in Victoria, B.C., and attended by over 20 government, industry and private sector scientists representing various disciplines relevant to BEMP Hypothesis No. 1. A full description of the workshop procedures, and resultant conclusions and recommendations is presented in PART 2 of this report. The overall conclusion of the workshop participants was that the hypothesis could not be presently rejected on the basis of available information, and that some evidence tended to reinforce the validity of certain links. As in the last workshop, emphasis was placed on the possible cumulative effects of offshore petroleum industry activities rather than site-specific disturbances.

It was recommended that studies to determine the annual differences in patterns of distribution of bowhead whales and their prey in the southeast Beaufort Sea should continue. Studies of the medium- and long-term behaviour responses of whales to both industry activity and food availability were also considered of value. Therefore, development of improved methods of tracking individual whales over the medium and long term was considered important.

Oil-base Drilling Muds Workshop/Conference

The planned workshop on oil-base drilling fluids was cancelled due to unanticipated government restraints during the latter part of the fiscal year. In lieu of this workshop, the following is included within PART 2 of this report:

1. a revised and more generalized hypothesis that describes the possible effects of oil-contaminated drill cuttings disposal on all marine resources of the Beaufort Sea rather than just anadromous fishes; and

2. summaries of research results discussed at two recent conferences:

    a) "Oil-base Drilling Fluids: Cleaning and Environmental Effects of Oil Contaminated Drill Cuttings" Trondheim, Norway, 24-26 February 1986.

b) "Environmental Effects of North Sea Oil and Gas Developments" Royal Society, London, 19-20 February 1986.

The revised hypothesis reflects possible direct and indirect effects of oil-contaminated cuttings discharge on a number of VECs including birds, marine mammals and fish. A generalized version of this hypothesis was considered necessary for a development scenario that could involve discharge of oil-contaminating cuttings in either shallow, nearshore or deeper, offshore areas of the region. The new hypothesis will be evaluated in detail in a future BEMP workshop.

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PART 1:

BOWHEAD WHALE WORKSHOP

INTRODUCTION

The impact hypothesis that relates bowhead whales to hydrocarbon development activities in the Beaufort Sea was formulated during the first year (1983-1984) of BEMP, and has been a focus of attention to the present time. The hypothesis has undergone only minor modifications since 1983 and is shown in Figure 1-1. It essentially states that industrial development, primarily sources of high frequency underwater noise, will reduce or prevent bowhead whales from reaching areas of high zooplankton densities in the southeast Beaufort Sea, which they require for growth, survival, and reproduction.

Since its formulation, the bowhead hypothesis has been evaluated during two BEMP workshops. The conclusion from the first workshop was that the hypothesis was valid and testable (INAC and Environment Canada 1984). Research programs were recommended in relation to the energy balance of bowheads, distribution of prey organisms and acoustical behaviour monitoring methods. Monitoring of the distribution and reproductive success of bowheads, their behavioural responses to industry activities and ambient noise levels were also recommended during this first workshop.

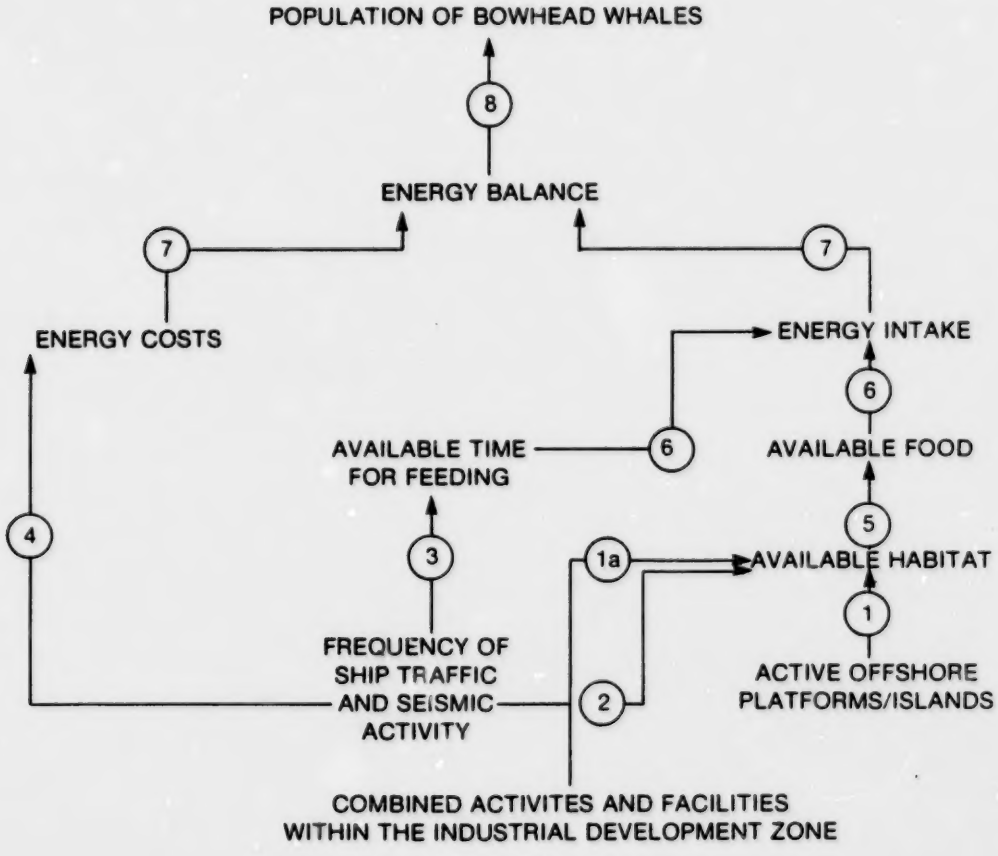
The conclusion of the second workshop was that the hypothesis and its associated linkages remained valid. A new link was added to the hypothesis during the February 1985 workshop. This link states that "the cumulative effect of all offshore industrial activities will be to create a large-scale zone of bowhead whale exclusion encompassing the entire industrial zone". It was added to underscore the increasing research emphasis directed at the cumulative effects of hydrocarbon development on bowheads, and at the same time, reflect the lower priority assigned to evaluation of short-term, site-specific impacts. Over the last two years, there is also further evidence that annual differences in the distribution of bowheads on their summer range in the southeast Beaufort Sea may be influenced or determined by a combination of physical and biological factors. Of particular interest are those factors influencing large-scale differences in the distribution and abundance of zooplankton, which are the primary prey of bowhead whales.

The workshop participants recommended that the priorities for research and monitoring in 1985 should be placed on: (1) continuation of systematic surveys and studies of long-term behaviour through aerial photography of individual whales; and (2) studies of food distribution and availability (in relation to oceanographic phenomena and bowhead distribution) (INAC and Environment Canada 1985).

FIGURE 1-1

POTENTIAL EFFECTS OF SHIP TRAFFIC, SEISMIC EXPLORATION AND ACTIVE OFFSHORE STRUCTURES ON BOWHEAD WHALES

Ship traffic, seismic exploration and active offshore structures will cause a reduction in the western Arctic population of bowhead whales



LINKAGES

1a.* The cumulative effect of all offshore industry activities will be to create a large-scale zone of bowhead whale exclusion encompassing the entire industry zone.

1. Each active offshore island or platform will exclude bowheads from a zone around the island/platform.

2. Ship traffic will exclude bowheads from a zone around the ship track.

3. Each passage of a ship will reduce the feeding time available to bowheads.

4. Each passage of a ship will increase the energy expenditure of whales due to avoidance behaviour.

5. The available aquatic habitat determines the level of available food.

6. The amount of available food and the time available for feeding determine the energy intake.

7. Energy intake and expenditures determine the energy balance of a bowhead whale.

8. The energy balance of a bowhead whale determines its survival and its ability to reproduce.

* This hypothesis link was added to more clearly represent the emphasis on the cumulative impact of hydrocarbon development on bowhead whales.

THE 1986 WORKSHOP

Approach

During the planning meetings for this workshop, the BEMP Management Committee and members of the study team discussed an overall approach that would result in formulation of research and monitoring recommendations to significantly accelerate the resolution of Hypothesis No. 1. These discussions focused on the three considerations described below.

First, it was recognized that there are theoretically at least two ways to test the hypothesis. The first is a statistical test and would be the ideal method of rejecting or accepting the hypothesis. The second method would rely on "circumstantial" evidence and can be considered the "weight of evidence" approach. In this case, monitoring and research are undertaken to amass a body of evidence that may be used to build a case for rejection or acceptance of the hypothesis. It is considered essential to acknowledge in advance the type of hypothesis test that will be applied to information collected during research and monitoring (statistical vs. weight of evidence). Monitoring and research programs recommended by BEMP to test the bowhead hypothesis have not involved with the direct measurement of proximate biological responses to industrial activities. Rather, they have been components of a measurement system that has focused on both the overall effect of industrial activities (e.g., bowhead whale distribution and population structure) and on the biological and physical characteristics of the preferred habitats of whales (e.g., zooplankton distribution and abundance; water temperature and turbidity measured directly and inferred through satellite imagery). It should also be noted that the series of distribution and population structure studies completed in the southeast Beaufort Sea have not been specifically designed to test BEMP hypothesis No. 1.

Second, it must be recognized during the design and execution of any research or monitoring program that there are three components to detecting an impact: (1) a real environment with its intrinsic natural variability, (2) a measurement system for obtaining biological information, and (3) an analytic model or framework for interpreting the observations. A rational, defensible research or monitoring program must employ a measurement system that is capable of detecting impacts in biological systems characterized by a high degree of natural variability. It is equally important to acknowledge the fact that data from a measurement system will never be completely accurate. Different measurement systems can be more or less suitable for testing of an impact hypothesis, but will never be perfect. Three sources of error must be recognized:

1. sampling error: For example, not all bowhead whales in the population can be counted during a systematic aerial survey, and assumptions are necessary about how representative the sampled population is to the entire population;

2. process error: For example, the degree of dependence of the annual energy intake on summer feeding of bowhead whales is an important process assumption; and

3. model error: For example, bowhead whale distribution may be determined by ice conditions rather than location of areas with high zooplankton densities or industrial activities, or due to a combination of the three factors.

The third consideration discussed in the workshop planning meeting is that monitoring and research programs are always constrained by available financial and logistic resources. As a result, there is an **ideal measurement system** and a **practical measurement system** and the latter is constrained by available resources. The sampling errors are larger with a practical measurement system, and process and model errors are also less likely to become apparent.

Workshop Activities and Procedures

The workshop to evaluate the bowhead whale hypothesis and provide recommendation for further research and monitoring was held 11-12 February 1986, in Victoria, B.C. The workshop was attended by the 23 participants listed in Appendix A. Following an introduction, the participants met as two individual groups throughout most of the workshop. Each group was first asked to design an ideal measurement system to test the bowhead hypothesis. Following a plenary meeting, at which the ideal measurement systems of the two groups were presented and integrated, the participants again met in separate groups to develop a practical measurement system to test the hypothesis. The practical measurement system differed from the ideal measurement system, since it considered logistical and budgetary constraints. At this stage, the subgroups attempted to define and document the inherent assumptions and the anticipated types of errors (along with estimated magnitude) associated with the proposed practical measurement system. The conclusions of each group concerning practical measurement systems to evaluate the bowhead hypothesis were then presented in a plenary session. Due to time constraints at the workshop, the practical measurement systems of the two groups were not formally synthesized into a single unified set of recommendations. Following the workshop, an integrated version of the practical measurement system of each group was prepared for the present report.

IDEAL MEASUREMENT SYSTEM

General Considerations

The measurement system designed to test the BEMP bowhead whale hypothesis must establish whether:

1. industry activity affects the energy balance of individual bowhead whales;

2. there is a change in reproductive success and/or longevity of affected individuals; and

3. changes in reproductive success and/or longevity of individual whales result in a change at the population level.

In order to test these items effectively, a control should be available to allow changes that are directly attributable to industry to be distinguished from those that are unrelated to industry operations in the region.

Ideally, a single measurement variable would be identified that, if monitored in conjunction with industrial activity, would provide a test of the BEMP hypothesis. An ideal variable, termed a Red Flag Parameter (RFP), was envisioned in the early stages of discussion and was defined as a parameter which, if changed, provided significant circumstantial or statistical evidence that an impact has occurred. The ideal RFP would have the following characteristics: (1) fast response to change; (2) relatively low natural variability; (3) a strong linkage to both reproduction and survival; and (4) a unique linkage to industrial activities. It is noteworthy that, even given the assumption of unlimited resources and technology, the group was unable to identify any candidate as a suitable red flag parameter for the bowhead whale hypothesis. However, the concept of this type of parameter within the ideal measurement system did influence the course of the discussion.

Although it was not a planned dichotomy, one of the two subgroups primarily discussed population level measurements, while the other focused on measurements at the individual level. The ideal measurement systems for each of these two levels of biological organization are summarized below.

Measurement Systems at the Population Level

Population Trends or Indices

In the simplest form, a statistical test of the BEMP hypothesis would involve concurrent measurements of the bowhead population and industry activity. However, the probability of detecting a statistically significant correlation between the bowhead population and industry activity was expected to be very low.

Over the last few years, researchers have attempted to determine the size of the western Arctic population of bowhead whales, using techniques of aerial surveys and ice platform-based counts during migration (both visual and acoustic census). Despite this considerable effort, constraints imposed by weather, resources and the census techniques themselves have limited the certainty of population estimates. Statistical confidence limits on the population estimates are large, and vary substantially from year to year. In an ideal measurement system, sampling effort could be increased, but uncertainties associated with natural variability in ice and weather would remain. As a result of these measurement uncertainties, in conjunction with the absence of controls (e.g., on predevelopment information) and the long life span of the bowhead, the effect of industrial disturbances would have to be large to detect any change at the population level. Even then, an effect may not be detectable until several generations have passed. It may not then be possible to link changes in population size to industrial activities. Thus, monitoring of population size, while necessary for resource management purposes, has little relevance to testing of the BEMP Hypothesis.

Other population indices were considered more viable for testing of the hypothesis, particularly those related to recruitment rates, and may be more sensitive for detection of significant changes in the population. Possible population-level indices include annual measurements of the number of calves and yearlings, either in the summer feeding grounds within the southeast Beaufort Sea or at times during spring and fall migration when the animals are concentrated in a small area (e.g., passing Barrow, Alaska). However, in view

of the natural variability and the difficulty in ascribing any change at the population level to a particular activity (e.g., industry), most participants were pessimistic that the hypothesis could be adequately tested using such indices.

Distribution of Whales and their Prey in the Southeast Beaufort Sea

Research and monitoring of the distributions of whales and their prey organisms in the southeast Beaufort Sea were expected to be a more promising means of testing the BEMP Hypothesis, although such a test would have to rely on the "weight of evidence". One experimental strategy would involve measurement of the food availability (zooplankton abundance) within and outside the areas of industrial activity, in conjunction with the distribution of whales throughout the Canadian portion of the Beaufort Sea. If few or no whales are present within the primary zone of industrial activity, as has been the case in the past few years, a measure of food availability inside and outside this zone would be useful. If the abundance of prey is greater outside the industrial area, the "weight of evidence" would then suggest that bowheads are not being displaced because of industry activities. However, if the availability of prey within these two areas is comparable or if zooplankton food resources are in fact more abundant in the industrial zone, then the BEMP Hypothesis may be valid. It was expected that studies of this type would be required for two to five years to provide sufficient "weight of evidence".

In conjunction with studies of the distribution of whales and their prey, the importance of particular feeding sites to bowhead whales was considered worthy of investigation. Studies were recommended to examine the biophysical conditions near the Yukon coastline and in Franklin Bay where numerous feeding bowheads have often been observed in recent years. This research should be directed at determination of the conditions that lead to good feeding habitat for whales. Studies of behavioural responses of whales to changes in food availability within congregation areas were also considered valuable to gain insight into the adaptability of bowhead whales to possible displacement by industry activities. Any consideration of the potential impacts from offshore industrial activities requires that the activities themselves are accurately recorded. Therefore, it was emphasized that detailed information on the location and types of industry activities in the Beaufort Sea should continue to be compiled each year.

Importance of Summer Feeding

There was considerable discussion of the need for studies to determine the importance of summer feeding to bowhead whales. Bowhead whales are believed to do most of their feeding during the summer when they occur in the southeast Beaufort Sea (INAC and Environment Canada 1984), although the evidence in support of this premise is largely circumstantial. At present, the proportion of the annual energy intake that bowheads derive from feeding in their overwintering areas within the Bering Sea and along migration routes is not known. As a result of this lack of knowledge, there is considerable uncertainty regarding the overall importance of the BEMP Hypothesis. For example, if the whales obtain a substantial proportion of their annual energy intake through feeding in the Bering Sea during winter, there would be less concern regarding the potential effects of industry activities in the southeast Beaufort Sea.

Two general approaches were discussed to determine the importance of summer feeding. Physiological and biochemical measurements (e.g., body girth, blubber reserves, stomach contents combined with lipase and carbon isotope analyses) of bowhead whales during the spring and fall migrations could provide information on the relative proportions of summer and winter feeding. Another approach would involve the use of aerial observation techniques in the Bering Sea during winter to determine if whales are feeding. It is unlikely that the observational studies would provide reliable quantitative estimates of relative difference between energy intake in summer and winter, and it is also uncertain whether such differences would be discernible using a biochemical measurement approach.

The results could be useful to assess the likelihood that bowheads may be significantly affected by reduced access to their prey in summer. It was recognized, however, that the studies related to the importance of summer feeding to bowhead whales would not directly test the BEMP Hypothesis. They would accordingly be relegated a lower priority than other BEMP recommendations.

Measurement Systems Involving Individual Whales

The ideal measurement system discussed by the second workshop subgroup was primarily directed at the level of the individual bowhead. The group reviewed various types of population research and concluded that any population level trends that might be detected could not be attributed to any one particular cause such as industry activities. The group believed that an ideal measurement system would have to include the capability to: (1) follow specific individual whales; (2) locate the individuals in space and time over a relatively long time frame (ideally years); (3) quantify behavioural reactions of bowheads to the presence of industry activities (stress, avoidance, displacement); and (4) quantify energy balance, reproductive success and survival. The ideal system would also require a sample of sufficient size and composition (calves, subadults, adults) to adequately represent the entire population.

As in previous BEMP workshops, the group concluded that there is presently considerable information on the short-term reactions (minutes to hours) of individual bowheads to industrial activity (e.g., Richardson et al. 1985). However, the longer-term behavioural responses of whales (if any) to the presence of industry in the region have not been examined. In order to undertake such studies, it would be necessary to readily identify individual whales either through natural markings (photography) or use of affixed transmitters (radio or satellite telemetry).

Although photography of naturally distinguishable whales does offer some practical advantages in that it is a technique that has undergone some feasibility testing, a reliable and long-term tag was considered a necessary component of an ideal measurement system directed at individuals. Such a tag could function as an effective tracer to locate known individuals within the range of the population and to track their movements relative to the location of oceanographic features and the areas of industry activities.

The workshop subgroup that emphasized the need for an Ideal Measurement System based on studies of individuals also discussed the benefits of an

integrated measurement system capable of quantifying energetic parameters and responses of bowheads to their environment. The group discussed a hypothetical "black box" that could be attached to a bowhead in the form of a tag and would provide instantaneous and/or integrated measures of relevant physiological parameters, as well as the precise location of individual whales on a real-time basis. Although it was recognized that such a device does not presently exist and may not be developed in the foreseeable future, the discussion was worthwhile in identifying the parameters that may eventually allow definitive acceptance or rejection of the BEMP Hypothesis. For example, the ability to locate and track individual animals through satellite reception of a transmitted signal would allow examination of the response to bowheads as they enter the southeast Beaufort Sea and approach the zone of industry activity. If various age classes of bowheads were tagged, it would be possible to obtain direct evidence to refute or confirm suggestions that the adult component of the population may be avoiding the industry zone. It is also conceivable that such a "black box" could be capable of recording industry-induced "stress" in the form of increased metabolic rates or some other parameter such as heart beat or elevated blood glucose levels. Ideally, the hypothetical satellite tag would also transmit information on energy intake and expenditure. While this tag is well beyond the present state-of-the-art, it was noted that considerable advancement in some of these technological development areas has been achieved recently (e.g., MacArthur et al. 1979; Falke et al. 1985).

The group also discussed a measurement system where the exposure of animals to industry activities over time would be determined through a factor termed "decibel days". In an ideal situation with an adequate sample size, indicators of the success of individual whales (e.g., energy stores, survivorship and reproductive success) could then be regressed against exposure to industry (decibel days) to quantify any effects of industry activities on bowhead whales.

Although the focus of this group's discussion was on the individual, it was recognized that some of the more "traditional" types of approaches discussed under Measurement Systems at the Population Level would be necessary to complement measurements of individual whales.

PRACTICAL MEASUREMENT SYSTEM

The discussion of the practical measurement system differed from that of the ideal measurement system through consideration of the logistical and budgetary constraints. Following discussion by the two subgroups and a plenary session, the practical system was subdivided into five major categories: Spatial/Temporal Distribution, Behavioural Response, Techniques for Tracking Individual Whales, Importance of Summer Feeding and Population Characteristics. Each category in the practical measurement system is discussed in some detail in the following sections.

Spatial/Temporal Distribution

The first practical measurement system is one which would document the spatial and temporal distributions of bowhead whales, industry activities and the prey (zooplankton) of bowheads.

Whales

The most direct method of obtaining evidence to reject the BEMP hypothesis involves determining the distribution of bowheads in relation to industry activities. If the distributions of whales and offshore activities regularly overlap, this would be strong evidence for rejecting the hypothesis. On the other hand, if aerial surveys continue to demonstrate that whales are located predominantly outside the industry zone, this will not necessarily provide the basis for acceptance of the BEMP hypothesis. Such surveys will, however, continue to provide some of the most fundamental data (i.e., the spatial distribution of whales through time) needed to assess the hypothesis.

Systematic Surveys

The workshop participants concluded that the current bowhead monitoring program (late August and early September systematic surveys and photogrammetric survey) should be continued for the following reasons:

1. BEMP Hypothesis 1 was formulated partly in response to a perceived decrease in the number of bowheads observed within the main industry zone between 1980 and 1983. Sightings from 1980-1983 systematic survey programs formed much of the database used to determine that a decrease in the use of the industry zone by bowheads may have occurred. The current monitoring program provides a relatively standardized dataset that can be used to determine the relative abundance of bowheads in areas within and outside the industry zone. Comparable data from six years of surveys (1980-1985) are presently available.

2. At this time, it is impractical to follow many individual bowheads. Even if 2-3 bowheads were tracked by telemetric means, the study of such a small number of individuals probably would not provide representative data for the entire population.

Systematic surveys provide an index of the relative abundance of bowheads in different parts of the southeast Beaufort Sea and should not be confused with attempts to estimate total population size. The group recommended that surveys be conducted at intervals of 10-14 days from about 1 August to 15 September, with emphasis on the period from late August to early September. Based on data from 1980-1985, this period encompasses the range of dates when most bowheads are expected to be present within the industry zone off Richards Island. The study area should include the continental shelf of the southeast Beaufort Sea and the zone off the Yukon coast west to 144°W longitude. It should also extend about 25 km north of the shelf break. In addition, the surveys should include the Franklin Bay/Cape Bathurst area to provide additional information on the temporal distribution of bowhead whales in an area away from industry activities. This area appears to be important since it is annually used by whales. It is thought that knowledge of whale use of the area, together with data on oceanographic conditions and food availability, would provide insight on factors that control the distribution of bowhead whales in the Beaufort Sea.

It was further recommended that local hunters and trappers be contacted to obtain qualitative information on the distribution of bowhead whales at

locations and times beyond those covered by the systematic surveys. Since recent monitoring programs have indicated that the majority of the bowheads found in areas covered by the systematic surveys are immatures, important information on the areas used by the adult segment of the bowhead population may be obtained from hunters and trappers.

Photogrammetric/Photographic Component of Systematic Surveys

Photogrammetric studies in recent years have demonstrated that there are major patterns of age, and possibly sex, segregation in the study area defined above. The animals that have occurred within and near the industry zone in recent years have been mostly young subadults. Few larger immatures, adults or young-of-the-year have been observed near the industry zone during recent surveys. This may or may not be the normal situation. Some workshop participants suggested a strong linkage of whales to areas with large supplies of food. Other participants suggested that, if whales are learning to avoid the area, large (i.e., older) experienced animals would be absent from the area. As a result, it was considered necessary to conduct photogrammetric studies in conjunction with the systematic aerial surveys to determine general patterns of age (= length) distribution in various parts of the study area. Photogrammetry techniques may also provide the opportunity to identify and re-identify individual whales with natural markings, although this was considered a secondary value of such research. Nevertheless, it may be possible to determine whether individuals use the same area or same habitat types within the year and/or in successive years (see Aerial Photography).

Documentation of Industrial Activity

Throughout the workshop, it was emphasized that assessment of the potential environmental impact of offshore hydrocarbon development will require adequate documentation of industry operations within the region.

Between 1980 and 1984, the U.S. Minerals Management Service (MMS) funded a compilation of all relevant data on the distribution of offshore industrial activities and bowheads in the southeast Beaufort Sea (Richardson et al. 1985a). This inventory of industry activities was continued during 1985 in a study sponsored by Indian and Northern Affairs Canada. As in past years, the inventory includes activities of the oil and gas industry, supply and transport services, and various research groups. The types of activities documented include (1) site-specific activities such as dredging, island or berm construction, drilling and island clean up; (2) vessel traffic including supply and crew boats, dredges, and icebreakers; (3) helicopter traffic; and (4) seismic exploration and related activities. All information will be retained in a microcomputer database to facilitate retrieval and presentation on maps and summary tables.

The importance of continuing and refining the present compilations of industry activities in the Beaufort Sea was accepted by the workshop participants.

Availability of Prey

A food availability study was recommended to provide information on the spatial and temporal distributions of marine zooplankton in the southeast

Beaufort Sea. Copepods and euphausiids are believed to be the major food sources used by bowhead whales in the region. The distribution of prey organisms should then be related to the distribution of whales. Previous studies indicate that bowhead whales graze in areas where there are above average densities of zooplankton. For example, Griffiths and Buchanan (1982) found that copepods were more abundant in areas where bowheads were feeding than in areas without feeding bowheads. Energy budget calculations for bowhead whales indirectly suggest that bowhead whales need to concentrate their feeding activities in areas with above-average amounts of zooplankton (Thomson 1985).

The abundance and biomass of zooplankton have been shown to be related to oceanographic conditions in areas where these relationships have been studied (Mackas et al. 1985). However, the biophysical mechanisms that result in aggregation of zooplankton are not well understood, and detailed studies of zooplankton distribution and abundance in relation to oceanographic conditions in the Beaufort did not start until 1985. Satellite imagery studies (Borstad 1985; Harwood and Borstad 1985; Thomson et al. 1986) in conjunction with aerial surveys of bowheads, have shown that whales are often observed near such observable oceanographic features as fronts, eddies or concentrations of brash ice. In addition, whale distributions occasionally appear to be influenced by the location of the turbid plume of the Mackenzie River and by the prevailing winds (Thomson et al. 1986; Project Overview No. 2). It is suspected that some of these apparent associations of whales with water mass features may be a reflection of associations between whales and areas characterized by relatively high zooplankton densities. Two studies conducted during the summer of 1985 in the eastern Alaskan Beaufort Sea and off the Yukon coastline (Project Overviews No. 3 and 4) included direct measurements of the distribution of zooplankton relative to concurrent measurements of water mass characteristics. These studies will provide valuable information regarding the distribution of bowhead whales in relation to zooplankton abundance and oceanographic features. However, both studies were conducted in known bowhead whale feeding areas, and neither investigation was intended to provide quantitative information on food availability within the areas of industry activity. Therefore, results of the studies will not conclusively refute or validate the hypothesis.

During the workshop, an experimental strategy was developed for a feeding study that would provide results which would contribute to a "weight of evidence" test of the BEMP hypothesis. Ideally, it would be desirable to obtain repeated synoptic coverage of the distributions of whales, zooplankton biomass, and water mass characteristics throughout the southeast Beaufort Sea, but this was dismissed as being logistically infeasible. For this reason, the group recommended that ship-based zooplankton sampling be limited to the following three regions:

1. the Yukon coast, where whales (mainly subadults) have been observed feeding each year since 1983;

2. Franklin Bay, where large adult bowheads have commonly been observed feeding; and

3. the industry zone north of the Mackenzie Delta, where most of the activities of the oil and gas industry and vessel movements occur.

Food availability (zooplankton biomass) in each area should be determined using a combination of traditional net sampling and hydroacoustic surveys. In this way, far larger areas can be sampled than would be possible by using traditional net sampling only, and the data would have finer horizontal and vertical resolution. In conjunction with zooplankton sampling, oceanographic and meteorological data should be collected both directly from the ship and remotely through the use of aircraft and satellite imagery. The satellite data, which provide synoptic coverage over a large area, will be important in allowing limited extrapolation of direct measurements taken in local areas to a larger region.

A separate study of food availability in the eastern Alaskan Beaufort Sea (Project Overview 1-3) is scheduled to continue and be completed in 1986. If the Canadian food availability study is conducted in 1986, results of the two projects will be complementary.

In conjunction with the food availability study, it was recommended that the response of bowheads to changing food conditions be examined. Detailed design of this research program would be based partly on the results of recent food distribution studies (Project Overviews 1-3 and 1-4), and partly on realtime observations during the period of the investigation (e.g., remote sensing and whale surveys). Zooplankton sampling should be completed with nets and hydroacoustic techniques, with calibration and interpretation of the acoustical data to allow for correction of the possible effect of scattering due to the presence of high concentrations of suspended sediments. The group also concluded that improvements in synoptic oceanographic measurements (temperature, salinity, turbidity, wind velocity structure) are needed to allow proper interpretation of study results.

Contribution to Hypothesis

The most direct methods of assessing the BEMP Hypothesis would involve determining whether bowheads are excluded from certain areas by industry activities and, if so, whether this exclusion affects their energy balance, reproduction or survival. If numerous whales occur near offshore industrial activities on a regular basis, they are probably not seriously affected and the hypothesis can be rejected. If the whales do not occur in the industry zone, they may be avoiding the area due to either activities in this zone or greater food availability elsewhere in the region. Therefore, direct monitoring of the use of the industry zone by whales, coupled with an assessment of food availability, will provide some of the most fundamental data necessary to assess the hypothesis. It is self evident that detailed compilation of the types, locations and extent of industrial activities must also continue to permit evaluation of the BEMP hypothesis.

The ship-based food availability study, completed in conjunction with the aerial surveys of whale distributions, should be designed to determine if comparatively low levels of prey availability in the industry zone may account for the small number of whales observed in this part of the Beaufort Sea. If relatively few whales are found in the industry zone, as in the past four years, and if food availability within this zone is comparable to or greater than that in areas where whales are located, this combination of results would provide evidence in support of the hypothesis that the whales are being excluded due to industry activities. On the other hand, if food levels were

consistently low in the industry zone in comparison with those in known feeding areas outside the industry zone, this would provide further evidence for the alternative hypothesis that the limited number of bowheads in the industry zone is attributable to limited food availability. In this case, the potential effects of petroleum industry operations on bowhead whales would be less of a concern.

Behavioural Responses

Medium-Term Response of Whales to Industry Activities

The participants in the previous BEMP workshop recommended that studies of short-term behavioural responses of bowheads to industry activities (Links 1, 2, 3, 4; Figure 1-1) be assigned a lower priority than some other studies. The rationale for this conclusion was that (1) information now available is sufficiently definitive to justify a shift in research emphasis; (2) the results of this research indicate that observable responses of bowheads to industrial activities are minor; and (3) results of further research of this type would not provide data that are essential to address the question of overall exclusion of whales from the industrial zone (Link 1a).

Although the present group did not disagree with the previous recommendation, some participants did want to qualify the rationale. The concern was that, although there is information on short-term reactions (minutes, hours), data on the medium-term (days, weeks) behaviour of individual whales are necessary for a proper evaluation of the validity of the lower links of the BEMP hypothesis.

Some whales have been observed in areas ensonified by ongoing industrial activities, which suggests that individual whales may habituate to continuous noise from ongoing industry operations. However, these results could also be obtained without habituation of bowheads. For example, (1) the whales observed on successive days may be different animals; (2) the whales may represent a small proportion of the number that would have been present in the area in the absence of industry; or (3) bowheads may not move rapidly away from sites of industry activity, but they may avoid returning to these locations.

Thus, the available information from short-term observations over a few hours indicates that the behaviour of bowhead whales is disrupted at least temporarily by transient industry activities. Medium-term observations show that some whales are present in areas ensonified by ongoing industry activities. However, it is not known if specific individual whales remain within ensonified areas for prolonged periods, or return to these areas in future years.

Participants discussed possible methods and approaches to obtain information about medium-term reactions of bowhead whales to industrial activities and to their food supply. It was generally agreed that information on the activities of identifiable individual whales would be required (see Techniques for Tracking Individual Whales).

Bowhead Response to Food Availability

The important question of how bowheads respond to availability of their prey can be evaluated in conjuction with studies of medium-term responses to industry activity and food availability (see above). It is essential that the food availability study include some detailed sampling of zooplankton in areas where bowheads are actually feeding. In conjuction with the sampling of prey organisms, comprehensive aerial observations of whale behaviour and aerial photography of bowheads should be conducted. The aerial component of the study is necessary because it is not possible to obtain reliable data on whale numbers, behaviour, and size from ship-based studies.

The objectives of this study should be to obtain detailed information on zooplankton species, quantities and densities in an area where bowhead whales are feeding. Aerial surveys should be used to determine the number of whales in the area and their distribution in relation to food resources. Observers participating in aerial surveys should quantify whale behaviour patterns using standard techniques (Würsig et al. 1984, 1985) to assess the types of feeding (e.g., bottom, water column or surface feeding) that occur and the characteristics of individual behaviour (e.g., surfacing-dive sequences, blow frequencies and sexual interactions per unit time). Aerial observations should continue for as long as whales are observed feeding in an area to determine changes in use of such areas with time. Participants also recommended repetitive sampling of zooplankton at specific intervals in areas where bowheads appear to be actively feeding. In this way, changes in patterns of whale behaviour may be related to differences in zooplankton densities.

The workshop participants expressed some concern regarding the potential that operations of a research vessel would influence the normal behavioural patterns of bowheads. Bowheads react strongly to rapidly-moving vessels, but are more tolerant of slow-moving vessels such as those that would be engaged in towing zooplankton nets (Richardson et al. 1985 and unpubl. data). To determine the response of whales to the research vessel, it would be desirable for the aerial observers to locate and document the behaviour of a group of undisturbed feeding whales before the vessel moves into the area to begin zooplankton sampling. This pre-sampling control plus the behaviour observations between the ship-based sampling periods should be useful to evaluate any effects of the sampling program itself on whale behaviour.

It is becoming apparent that important habitat-related patterns of age segregation occur on the summering grounds of bowhead whales in the southeast Beaufort Sea. Small, subadult animals occur commonly in shallow, turbid waters, whereas most adults are present in deeper, clear water. The energy requirements and feeding behaviour of individuals of various age classes may be quite different. Thus, it will be important to determine the relative ages of the animals being studied to assess whether major differences in habitat utilization are reflected in different food requirements. Aerial photogrammetric techniques can be used to document the length distribution of bowheads and thereby establish relative age. Photographs should be taken at the end of each aerial behaviour observation session.

The workshop participants recommended examination of the behaviour of individual animals over a period of days when they are present in a feeding

area. The preferred approach would involve the use of radio tags that can be monitored for a period of a few weeks. However, the art of applying a semi-permanent tag to bowhead whales is not perfected, the effect of application of the tag on whale behaviour is unknown, and a second research vessel would be required since the main vessels would be fully committed to marine sampling. All of these factors prohibit use of tags to investigate this problem in the near future. An alternative approach would be the use of individual identification of animals based on the aerial photographs taken at the end of each behavioral observation period. These photographs would provide some use information on the use of the feeding area by individuals and turnover rates of animals in the area. This technique is limited in that not all individuals can be recognized, but some members considered it the most feasible alternative that is presently available.

The precise details of this recommended study cannot be planned until the design of the food availability study described earlier is completed. The final program design will obviously depend on available research vessels and budgets. Insofar as practical, the methods should be consistent with those employed in other past and ongoing studies of bowhead feeding behaviour. The logistics of this study on the responses of bowheads to food would also depend on whether a study of medium-term behavioural responses to industry activity was being conducted.

Contribution to Hypothesis

Although several studies have documented the short-term behavioural reactions of bowheads to industry activities (Ljungblad et al. 1985; Richardson et al. 1985 b,c, 1986), the observations have been of limited duration (i.e., 1-3 h), primarily because of the practical constraints of tracking individual animals. However, the medium-term (days or weeks) behaviour of bowhead whales within the industry zone is not well enough understood to allow a full evaluation of the validity of Links 1, 2, 3, or 4 (Figure 1-1). It is also difficult to assess the potential relationships between specific behavioural responses and long-term cumulative effects (Link 1a). The success of any studies of medium-term behavioural responses of bowheads to industry activities, and ultimately their usefulness in terms of testing the BEMP hypothesis, is contingent on the ability to track individual whales. The advantages and limitations of various tracking techniques (e.g., photography, tagging) are discussed in a subsequent section addressing Techniques for Tracking Individual Whales.

Previous studies (Griffiths and Buchanan 1982; Bradstreet, in prep.) of the distributions of the prey of bowhead whales in 1980, 1981 and 1985 have provided information regarding food availability in certain areas, and limited information on the correlation between the numbers of bowheads and the quantity of available prey. These studies were hampered by the lack of data on (1) the densities of zooplankton necessary to support feeding bowheads and (2) the mechanisms through which bowheads locate and respond to various densities of food. The recommended study of bowhead responses to food will provide the first direct estimates of the minimum prey densities necessary for feeding individuals and groups of bowheads. This information will be important in evaluation of the results of the food availability studies, particularly in determination of whether the absence of whales from an area is related to the lack of an adequate food supply.

Techniques for Tracking Individual Whales

Three potential techniques for identifying and tracking individual whales were discussed during the workshop: (1) recognition of naturally marked whales using photography; (2) the use of conventional radio tags; and (3) the development and deployment of satellite-tracked tagging devices.

Aerial Photography of Naturally-marked Whales

This approach is a proven technique that can lead to occasional re-sightings of individual well-marked (i.e., scarred) bowheads. Intensive photographic programs can also produce useful data on day-to-day recurrence and movements of animals, and smaller numbers of year-to-year re-sightings. The technique also has the advantage that it is unnecessary to approach and potentially disturb the animals. However, it cannot provide continuous position information, and has major limitations with respect to the ability to re-sight whales in turbid water. Therefore, it cannot be established how long a whale remained at a particular location. It is also only useful for re-identification of older animals. Because bowhead whales are usually unmarked and unrecognizable until they are relatively old, there have been relatively few year-to-year re-sightings to date. At present, most of the between-year re-sightings have resulted from re-sightings in 1985. The photo catalog of recognizable bowheads was greatly increased in size during 1985, and the frequency of re-sightings should be higher in future years. As an illustration, the between-year re-identifications of bowheads from photos taken in the southeast Beaufort Sea was approximately four up to and including the summer of 1984. However, there are now approximately 16 year-to-year re-sightings following the analysis of 1985 photos (R. Davis, pers. comm.).

It was suggested that photography could be undertaken as one component of aircraft-based studies of bowhead distribution or behaviour. Over time, the occasional re-sightings of recognizable whales obtained during 'multi-purpose' aerial programs would prove useful for evaluating day-to-day and year-to-year patterns of recurrence and movement of bowheads, in the same way that the gradual accumulation of photos of recognizable humpback whales has led to considerable advances in the understanding of their movements (e.g., Darling and McSweeney 1985).

Tagging

Many participants placed considerable emphasis on the advantages of a radio or satellite tag. Tagging was identified as a technique that could be useful to obtain information on the following:

1. short- or long-term movements;
2. activity 'budgets' such as the proportion of time spent in various behavioural modes such as feeding or resting at the surface;
3. relationships between the distributions of whales and oceanographic features; and
4. responses of whales to food availability and industry activities.

At present, however, there are major constraints that were expected to greatly reduce the likely success of tagging in producing useful information over the next few years. The first limitation is one of sample size. The number of animals that would have to be tagged to provide representative population-level data is unknown. It was considered likely that the minimal requirement would be for data on 10's of animals. Because of fiscal and other constraints (i.e., tagging success, see below), the likelihood of radio and especially satellite tagging an adequate number of animals was considered low. Thus, the principal value of tagging would be to produce medium- or long-term (i.e., weeks to months) data for a few individuals.

Satellite Tags have the potential to provide data on large-scale, long-distance movements of whales without the need to follow the animals from a boat or aircraft. This approach is also likely to be more cost effective in the long term and will yield more information by virtue of the high information content and regularity of data transmitted from a satellite.

On the other hand, satellite tags are larger, more expensive, and more difficult to deploy than conventional radio tags. The technology and methods for satellite tagging are still under development, and although the electronic components for these devices have been developed over the past few years, a successful tag and attachment of that tag have yet to be demonstrated.

Some participants believed that the development of a reliable long-term tag (one year plus) was very important. However, other workshop participants anticipated that, although satellite tags may ultimately be very useful, an intensive satellite tagging effort would be unlikely to provide many data in the immediate future relevant to the BEMP Hypothesis.

Conventional radio tags provide information about the bearing to the tagged whale only at times when the tag is above the water surface. From this information, a radio-tagged animal can be located, and its surfacing-dive sequences can be roughly monitored. The limiting factor to the use of radio tags is usually not battery lifetime (weeks or months), but rather the difficulty of securely attaching the tag to the whale. In addition, the detection range for VHF tags is limited by line-of-sight, and is several kilometres from a small boat and several tens of kilometres from an aircraft. The detection range for HF tags is somewhat greater. In either case, a boat is needed to approach the whale to deploy the tag, and either a boat or aircraft is required to track the whale. It was concluded that this could be logistically difficult and costly.

Conventional radio tags have not been applied successfully to bowhead whales, although the group recognized that there has been only one serious attempt to do so (Hobbs and Goebel 1982). A smaller and more readily deployable radio tag has been developed recently (Goodyear 1985). It has been tested successfully with fin and gray whales, and it is to be used in the U.S. Minerals Management Service bowhead feeding study in the Eastern Alaskan Beaufort Sea (Project Overview No. 3). There were no good opportunities to deploy it during the first season of that study (September 1985), but radio tagging is to be attempted again in September 1986.

Participants believed that the conventional radio tag approach had the potential to provide useful data on the medium-term responses of bowheads to

industry activities or to changing food resources. The use of conventional radio tags was considered a better alternative than satellite tagging for applications in the near future. Data collected in support of medium-term behavioural response studies could include information on residence times, surfacing-dive sequences, movement patterns near fixed sites of industry activity, movements during and after displacement by boats, and responses to repeated approaches by marine vessels. Control data could be acquired through sequential observations of the same individual tagged whales before or after exposure to industry activity, simultaneous observations of different tagged whales outside the industry zone, or through both of these approaches.

Contribution to Hypothesis

It was suggested that while the results of a tagging program may not allow statistical testing of the overall BEMP hypothesis, this approach could be a powerful tool in collecting useful data for a "weight of evidence" analysis. The discussion of techniques for tracking of individual whales focused on two areas of emphasis.

The first topic of discussion was the need for development of a long-term (one year plus) with relatively modest temporal resolution to address questions related to migration routes, calving interval, feeding behaviour, and residence times within and outside the industry zone. Given the limited information on the movements and basic biology of bowheads, many participants expressed strong support for the development of a long-term tag to gain knowledge at the individual level. This would contribute to the "weight of evidence" analysis of several links in the hypothesis, but was expected to be a relatively long-term program.

The second area of emphasis in the discussion was on an identification/tracking technique that could be used in the near future as part of other recommended studies discussed in this report. Deployment of a reliable tag would be important, if not essential, to adequately document behaviour such as the medium-term reaction of whales to industry activities and their responses to food resources. Each of these studies addressed the lower linkages of the BEMP hypothesis, as well as the alternative hypothesis that bowhead whale distribution within the southeast Beaufort Sea is determined by the distribution of its food resources rather than the location of industry operations and facilities in the region.

Photography was discussed as a tool with similar but more limited application to long-term (between years) and medium-term (within years) distributional trends. Although identification of individual animals using photography has several disadvantages compared to tagging, it is currently the only method that has any proven success with bowhead whales, and for which there is an existing database. Nevertheless, it was concluded that photos of bowheads should be taken on an opportunistic basis during other aerial studies (particularly photogrammetric investigations) to allow reidentification of bowheads where possible.

Importance of Summer Feeding

As indicated in the discussion of the Ideal Measurement System, further information regarding the importance of summer feeding in the southeast Beau-

fort Sea is considered important for a "weight of evidence" assessment of BEMP Hypothesis No. 1. If bowheads feed almost exclusively in this region (INAC and Environment Canada 1984), any significant interference in summer feeding could be of importance to the population. On the other hand, if bowheads obtain a substantial proportion of their annual energy intake during winter in the Bering Sea, the possible energetic implications of such interference in feeding activities would be correspondingly reduced.

Girth Measurements Derived from Photography

Workshop participants concluded that some temporal index of the energetic condition of bowhead whales is required to determine the importance of summer feeding. The ideal measurement system would involve the evaluation of the energy balance of individual animals over time to quantify the proportion and relative importance of summer feeding. Despite the fact that this is currently not practical, the National Marine Fisheries Service is analysing 3-dimensional photographs in an attempt to achieve an approximation of body girth (M. Nerini, pers. comm). High-quality photographs of whales in clear water may also allow for accurate measurements. The technique has proven viable for test targets on land, although it remains unproven in most field applications and would be ineffective for bowheads in turbid waters. Studies of other cetacean species suggest that the girth of the area immediately anterior to the peduncle may be a reliable index of total body fat. While this approach would not permit quantification of the extent of winter feeding, if proven practical, it could provide some evidence of the comparative energetic condition of whales during spring and fall migration given a suitable sample size.

Physiological and Biochemical Studies of Harvested Whales

Physiological and biochemical information obtained from the few whales harvested in the Alaskan Beaufort Sea in spring and fall could help determine the relative importance of summer and winter feeding by bowhead whales. This approach would provide much more detailed information than the aforementioned remote measurements of girth, but these detailed data would be for a much smaller sample of animals.

Potentially useful information that could be obtained from harvested whales is included in the following table.

Measurements of composition of blubber and blubber thickness will provide estimates of the net change in stored energy during winter. If no discernible differences between spring and fall whales are found, this would be circumstantial evidence that significant feeding occurs in winter. However, interpretation of comparative measurements on animals harvested in spring and fall could be hampered if blubber thickness decreases as a result of the migration of bowheads from the Bering Sea.

One workshop participant felt that zooplankton in the eastern part of the Alaskan Beaufort Sea are isotopically dissimilar to zooplankton from the Bering and Chukchi seas. Studies have been initiated to determine the isotopic composition of zooplankton from the southeast Beaufort Sea. Since the carbon isotope abundance is conservative within a food chain, any alternation of isotopic abundance in a whale after leaving the Beaufort Sea

Sample	Type of Analysis
1. blubber thickness in tail peduncle	thickness in cm
2. blubber	% lipid total and degree of saturated fats, carbon isotope analysis
3. visceral fats	carbon isotope analysis/ saturation
4. muscle	carbon isotope analysis
5. pancreas (whole, frozen)	lipase analysis
6. bile (0.5 litre), liver	possibly lipase analysis
7. stomach contents	species analysis/carbon isotope analysis

would be indicative of food consumption in the winter range. If a body constituent such as muscle tissue or fat shows consistent seasonal variability in carbon isotope abundance, it may be possible to obtain semiquantitative estimates of the relative importance of feeding in each habitat.

The waxy esters that are the main energy storage compounds in copepods are normally non-digestible by mammals. Although it is probable that bowhead whales possess the lipases essential for the digestion of these esters, their presence has not yet been demonstrated. Samples of bile and/or pancreatic tissue should provide materials for the enzymatic assays necessary to document the presence or absence of the lipases that cleave the esters prevalent in copepods. If bowheads lack these lipases, estimates of the necessary food intakes and zooplankton densities for feeding would have to be altered accordingly.

Additional analyses of stomach contents of whales harvested in fall and spring could provide information on feeding locations and patterns. Of particular interest is the possibility that bowheads are herbivores in early spring when the diatom bloom occurs. Data on the species composition and sizes of prey organisms could also be combined with an evaluation of the energy content in ingested food in order to refine present estimates of energy intake. In addition, determination of the carbon isotope abundance in prey organisms would be useful in evaluation of the relative importance of feeding in different geographic locations.

Contribution to Hypothesis

The group concluded that research in this area was important to pursue, although information on the importance of summer feeding would not directly assist in testing or evaluation through "weight of evidence" of the

BEMP hypothesis. This hypothesis suggests that industry activities will limit the feeding opportunities of bowheads in the southeast Beaufort Sea during the summer, and will in turn have energetic implications that ultimately affect the population (Links 5, 6, 7, 8; Figure 1-1).

Bowhead whales are believed to obtain the majority of their annual energy intake through feeding during the summers (INAC and Environment Canada 1984). There is, however, only circumstantial evidence in support of this hypothesis. For example, in both hemispheres, all other species of baleen whales that migrate to high latitudes for the summer do most of their feeding in this period. Alternatively, there is limited information on the feeding of bowheads during the period when they are outside of the Canadian portion of the Beaufort Sea. This evidence has been obtained from a few stomach samples of whales harvested in Alaska during spring and fall migration (Lowry and Frost 1984). Therefore, the extent of feeding of bowheads outside the southeast Beaufort Sea remains largely unknown.

The studies described above could, if successful, provide some "weight of evidence" concerning the relative importance of the Beaufort Sea for feeding by bowhead whales. It should be recognized that each of the recommended research programs would be conducted off Alaska and not within the southeast Beaufort Sea; and each involves considerable inherent uncertainties and assumptions in terms of experimental techniques and the adequacy of sampling effort. Moreover, it would be impossible to attribute any changes in energy levels or physiological conditions of bowheads directly to industry activity. Therefore, these study approaches would not provide the data needed for acceptance or rejection of any specific link in the BEMP hypothesis. Nevertheless, several workshop participants believed that continuation of the ongoing data collection programs would be worthwhile for various reasons only partially related to BEMP, although their relevance and usefulness to the BEMP hypothesis itself were considered tenuous. Research in this area could be useful to fill gaps in knowledge concerning the general biology and physiology of arctic whales and, therefore, increase our general knowledge of factors that may influence the abundance and distribution of whales.

Population Characteristics

Population Trends and Indices

Although it was generally agreed that the ultimate test of the BEMP hypothesis would be reduction in the size of the bowhead population, the group concluded that such changes would be very difficult to measure and impossible to relate directly to industry activities in the region. Some of the limitations an assumptions related to monitoring of the total population were discussed earlier under Measurement Systems at the Population Level.

The most practical location to monitor population size is at Barrow, Alaska, during the spring migration of bowheads. The group noted that recent improvements to the visual census at Barrow and the addition of acoustic detection methods may lead to refinements in the census techniques and improvements in their precision. It was generally agreed, however, that until such improvements in precision are achieved, it is not worth monitoring total population size to evaluate the BEMP Hypothesis.

It was suggested that some index of the population size might be monitored as a surrogate for total population size to indicate trends in the population. Analogs to catch per unit effort (CPUE) based on sightings per unit effort (SPUE) were discussed among the group. Since no data based on SPUE have been examined to date and there are significant concerns regarding possible age, sex, behavioural, temporal and geographic biases, it was recommended that measures of SPUE or other indices not be pursued at the present time.

In long-lived species such as whales, measures of reproductive success are generally more sensitive indicators of population change than are estimates of total population size. Published estimates of reproductive rates are biased by some combination of age and sex segregation in the population, as well as by problems associated with detectability. The bowhead reproductive study in 1985 (see Project Overview No. 1-5; Davis et al., in prep.) was designed to quantify these biases and determine an unbiased estimate of reproductive rate. The results of this study are not yet available. It is not possible, therefore, to evaluate the sampling error and confidence limits that will be associated with these estimates of reproductive success.

If the confidence limits are very wide, it will be difficult to evaluate small changes in reproductive success from year to year. On the other hand, if the confidence limits are narrow, it may be worth pursuing this type of measurement. However, the problem of relating changes in reproductive rates to industry activities will remain, making this approach less than ideal for addressing the BEMP Hypothesis.

Contribution to Hypothesis

Measurements of change in the size of the bowhead population (or a reliable index of population) that could be directly attributed to industry activities in the Beaufort Sea represent the ultimate test of the BEMP Hypothesis. However, such a test was not considered feasible for a variety of theoretical and practical reasons. While ongoing improvements in measurement techniques should be evaluated for possible future relevance to BEMP, the workshop participants could not identify any practical measurement systems for population parameters that are of direct relevance to an evaluation of the Hypothesis.

PRESENT MEASUREMENT SYSTEM

In the 1985 BEMP workshop, a large amount of research relevant to the bowhead whale hypothesis was reviewed and discussed on a project by project basis. This approach was altered for the present workshop to greater emphasis on the design of ideal and practical measurement systems. Nevertheless, since the principal investigators of almost all relevant research programs were present, the preliminary results of 1985 studies were naturally reviewed as part of the workshop discussions. The results of recent investigations were not, however, presented on a project by project basis, with the exception of two new and directly relevant studies of zooplankton distribution and abundance (see Project Overviews 1-3 and 1-4).

Table 1 lists present research projects which together constitute the 'Present Measurement System'. These projects are described in detail in Part 3 of this report.

Table 1. Present measurement system as reflected by present bowhead investigations.

Project Overview Number	Title and Author(s)	Research Topic(s)	Description
1	1985 bowhead whale monitoring studies in the southeast Beaufort Sea. Duval *et al.*, 1986.	Distribution and Abundance	The sixth consecutive year of systematic surveys, including coincident satellite imagery and aerial photography.
		Photography/Photogrammetry	Measurement of lengths of whales throughout the study area from aerial photography.
2	Factors determining bowhead whale distribution in the Beaufort Sea: a feasibility study. Thomson *et al.*, 1986.	Bowhead Feeding/Oceanography	Factors that may influence zooplankton distribution and, therefore, feeding of bowhead whales.
3	Importance of the eastern Alaska Beaufort Sea to feeding bowheads. Richardson *et al.*, in progress.	Bowhead Feeding/Oceanography	A two-year project to quantify the proportion of energy requirements of W. Arctic bowheads provided by food resources of E. Alaska Beaufort: studies of zooplankton distribution and utilization of the area by bowheads.
		Photography/Photogrammetry	Immediate identification of individual whales.
4	Food availability characteristics of the offshore Yukon coast to the bowhead whale. Bradstreet *et al.*, in prep.	Bowhead Feeding/Oceanography	Determination of the importance of the Yukon nearshore and adjacent marine areas in relation to the energy requirements of bowheads.
5	Reproductive parameters of the bowhead whale and the status of the Western Arctic bowhead whale population. Davis *et al.*, 1986.	Photography/Photogrammetry	Estimation from aerial photographs of gross annual recruitment rate, proportion of yearlings, geographic segregation by age class and reproductive status, and calving interval of W. Arctic bowheads.

continued . . .

Table 1 (continued)

6	Bowhead migration monitoring. Davis and McLaren, 1986.	Distribution and Abundance	Aerial surveys in Alaskan Beaufort Sea to determine bowhead distribution and behaviour near inactive drillsite during fall migration.
7	Bowhead migration monitoring. Davis and Johnson, 1986.	Distribution and Abundance	Aerial surveys in Alaskan Beaufort Sea to determine bowhead distribution and behaviour near artificial island during fall migration.
8	Bowhead migration monitoring. Holdsworth and Allston, 1986	Distribution and Abundance	Aerial surveys in Canadian Beaufort Sea to determine how late in season bowheads remain there.
9	Relationship between bowhead whale distribution during fall migration and surface oceanography of northern seas as seen by satellite imagery. Borstad, in prep.	Bowhead Feeding/Oceanography	Use of satellite imagery to correlate oceanographic features and bowhead distribution.
10	Assessment of the two-stock hypothesis via commercial whaling records. Fraker *et al.*, 1986.	Distribution and Abundance	Analysis of historical records of commercial whalers to determine whether there was a separate stock of bowheads summering in the Bering and Chukchi seas as well as the present stock in the Canadian Beau- fort Sea.
11	Historical variability in summer bowhead distribution. Fraker *et al.*, 1986	Distribution and Abundance	Comparison of historical and present variability in summer distribution of bowheads.
12	Feasibility of tagging bowhead whales for tracking by satellite. Mate, in progress.	Tagging	Satellite tags applied to one humpback and two gray whales: an attempt may be made to tag bowheads.

continued . . .

Table 1 (concluded)

13	The long-term effects of offshore industrial activities on bowhead whales in the Canadian Beaufort Sea. Davis *et al.*, 1986	Photography/Photogrammetry	Application of a photographic identification technique to examine medium- and long-term response of bowheads to offshore industrial activities.
14	Assessment of the value of stratified sampling for aerial surveys: a case study of bowhead whales in the Beaufort Sea. Oguss and Robertson, 1985.	Distribution and Abundance	Re-examination of existing data to assess 1) stratification of the study area to improve population estimates and 2) redistribution of sampling effort.
15	Marine mammal remote sensing techniques. Yaremchuk, in progress.	General	Development of optimal photographic and infra-red techniques for monitoring marine mammal distribution in relation to offshore hydrocarbon activities, and investigation of relationships between arctic marine mammals and their habitat.
16	Foraging behaviour of grey whales in relation to patch dynamics of their benthic prey along Vancouver Island, British Columbia. Guerrero, 1985.	Feeding Behaviour of Other Baleen Whales	Quantification of feeding and other behaviour of grey whales in relation to diver-identified patches of mysids.
17	Food and feeding of right whales in Cape Cod Bay, Massachusetts. Mayo *et al.*, 1985	Feeding Behaviour of Other Baleen Whales	Use of videotape to monitor whales feeding on zooplankton patches

CONCLUSIONS

The workshop participants concluded that BEMP Hypothesis No. 1 and its linkages remained valid.

Research and monitoring efforts should continue to document the annual patterns of whale distribution in the southeast Beaufort Sea and to provide additional information on the relationships between bowhead whale distribution in summer to food availability. Studies of the behavioural responses of whales to both industry activity and food resources were also considered an important area of research. In this regard, the development of improved methods for tracking individual whales over the medium and long term (many days, years) was also supported by many participants.

RECOMMENDATIONS

The following list of recommended research and monitoring programs evolved from discussions of practical measurement systems:

A) Summer Distribution of Bowheads in the Southeast Beaufort Sea:

1. aircraft-based surveys of bowhead whale distributions;

2. documentation of offshore industry activities;

3. ship-based study of the availability of food (zooplankton), within and outside areas of industry activity; and

4. survey of local hunters and trappers to obtain information on the occurrence of bowhead whales at locations and times outside of those covered by the research and monitoring programs.

B) Behavioural Studies:

5. a study of medium-term responses of whales to industry activity;

6. a study of the response of bowhead whales to food availability to obtain estimates of minimum zooplankton densities in areas where bowheads feed; and

7. development of satellite and radio tags for application to the existing problems of tracking individual bowhead whales over extended periods. Photo identification was recommended only if photos could be collected on an opportunistic basis as a component of other aerial projects.

C) Importance of Summer Feeding:

Studies to examine the potential application of the following techniques to the question of the importance of summer feeding to bowhead whales were encouraged. It was recognized, however, that the techniques themselves are largely unproven, and that the relationship of studies using these approaches to the BEMP hypothesis would be indirect.

8. photographic measurements of the girth of bowhead whales; and

9. collection of physiological and biochemical data from harvested whales.

It is emphasized that in order to effectively address the BEMP hypothesis, bowhead studies must be closely co-ordinated. Some studies listed above are very closely associated and could in fact be considered related components of a more comprehensive research strategy. These include studies 1, 3 and 6; and studies 5 and 7.

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APPENDIX A

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PART 2:

THE ENVIRONMENTAL EFFECTS OF OIL-CONTAMINATED DRILL CUTTINGS IN THE NORTH SEA

INTRODUCTION

The following summary of the environmental effects of oil-contaminated drill cuttings in the North Sea is based on the results of research presented at two conferences in February, 1986: (1) Environmental Effects of North Sea Oil and Gas Development, a discussion meeting held at the Royal Society, London (19-20 February); and (2) Oil-based Drilling Fluids: Cleaning and Environmental Effects of Oil Contaminated Drill Cuttings held in Trondheim, Norway (24-26 February). The latter conference represented the completion of a three-year joint research project involving the Norwegian State Pollution Control Authority (SFT) and the Statfjord Unit, a consortium of 13 oil companies with interest in the Statfjord oil field. The purpose of this study was to examine the environmental effects of using oil-base drilling fluids and evaluate possible methods for reducing any identified negative effects. In contrast, the scope of the discussion at The Royal Society meeting was much broader than that at Trondheim, addressing all aspects of environmental effects of North Sea oil and gas developments including the effects of oil-contaminated drill cuttings.

The information presented in this summary is based on the oral presentations at the two conferences, written abstracts or papers submitted, the question and answer period following the oral presentations, and informal discussions with authors of papers and research scientists present at the conferences. The summary focuses solely on information related to the marine disposal of oil-contaminated cuttings that is considered relevant to the Beaufort Environmental Monitoring Program.

GENERAL OVERVIEW OF NORTH SEA STUDIES

The objectives of most monitoring programs in the North Sea have included:

1. Biological Objectives: To describe, in a quantitative manner, the macrobenthic species, their abundance, spatial distributions and long-term population dynamics; to provide comparative data for successive surveys; and to determine the effects of underwater industry structures on benthic fauna.

2. Chemical Objectives: To establish the natural levels and chemical nature of hydrocarbons (and selected metals to a much lesser extent) surrounding oil and gas production platforms; and to determine the degree and probable sources of hydrocarbon contamination around platforms.

There has been only limited sampling of the water column as part of effects monitoring programs in the North Sea. It has generally been concluded that the sources of natural variability in water column parameters cannot be adequately addressed in sampling and, therefore, it is not possible to distinguish the effects of oil field operations from those associated with natural variability.

Extensive benthic faunal studies have been an integral part of most monitoring programs in the North Sea. A recognition of the usefulness of accumulating (sediments, sedentary biota) rather than dispersing media (water

column) has been, in large part, responsible for the emphasis on benthic studies. Studies of benthic fauna have generally been completed in conjunction with sediment chemistry monitoring which has been used to provide an early warning of potential environmental harm, because elevated levels of hydrocarbons and heavy metals in sediments are usually detected long before they have any measurable effect on the structure of benthic communities. Although there has been a high degree of variability in the results of almost all benthic faunal studies conducted to date in the North Sea, definite trends in the effects of oil-contaminated cuttings have been identified and zones of influences of these discharges can be delineated.

Information presented at the conferences included results of field surveys, experimental field studies and laboratory studies involving cuttings contaminated with either diesel-base or mineral oil-base muds. Diesel oil of the type used in drilling fluids in the North Sea consists of normal paraffins (largely within the range C_8 to C_{26}), approximately 21% aromatics and 79% saturated hydrocarbons. The amount of hydrocarbons on diesel-contaminated cuttings averages about 10% on a wet weight basis. Mineral oil of the type used in drilling fluids in the North Sea contains at least 90% normal paraffins in the range C_{13} to C_{15}, about 5% aromatics and 95% saturated hydrocarbons. The amount of hydrocarbons on cuttings contaminated with mineral oil is approximately 23% on a wet weight basis.

The overall conclusion of the studies conducted to date on the environmental effects of oil-contaminated drill cuttings in the North Sea is that, although disruption of the benthic environment due to hydrocarbon contamination is measurable, the extent of the disruption is far less than originally expected. Significant effects of discharges on benthos located distances greater than 1000 m from a production platform have been demonstrated in only a few cases. In contrast, elevated hydrocarbon concentrations in sediments can be detected up to 5 km from platforms. At a recent meeting of the OECD ministers, a list of important environmental issues in the North Sea that require action was prepared; cuttings contaminated with oil-base mud did not appear on the list.

Field Studies

A comprehensive study of the benthic fauna around the Statfjord oil field conducted by the Institute of Offshore Engineering at Heriot-Watt University (Matheson *et al.* 1986) provides a clear indication of the response of a benthic community to the presence of oil-contaminated cuttings. The Statfjord oil field development has taken place in a phased manner with the installation of three platforms (Alpha, Bravo, Charlie) over a seven-year period. This development presented a rare opportunity to study the effects of oil-contaminated drill cuttings in a range of circumstances in which:

1. both diesel and "low toxicity' (mineral) oil-base drilling muds had been used (Statfjord Alpha);

2. only diesel oil-base muds were used (Statfjord Bravo); and

3. drilling had not yet commenced but where only "low toxicity" oil-base drilling muds will be used.

There were two main trends in the distribution of benthic fauna around the Alpha and Bravo platforms: (1) a decrease in the abundance of individuals with increasing distance from the platforms, and (2) an increase in species abundance and diversity over the same distances. The number of individuals and species varied little from station to station around Platform Charlie. Three groups of species could be clearly distinguished around the Alpha and Bravo platforms. The first group are opportunistic species present in very high numbers close to the platform in areas of high organic enrichment, and are small organisms that are able to colonize and exploit environmentally disturbed areas. This is because of their very short life cycles, and their ability to reproduce vegetatively, or alter their reproductive strategy to suit conditions. These species are very important because their enormous abundance and high productivity is a major factor in the eventual degradation of organic contaminants. A second group of species are largely intolerant of polluted conditions and do not compete with the opportunistic species where the environment is disturbed. Their numbers are limited by both inter- and intraspecific competition. The third group of species are thought to be organisms more tolerant than those confined to the completely uncontaminated sediments (Group 2), but are unable to reproduce rapidly enough to exploit recently disturbed areas. They reach their maximum numbers in the zone where they can outcompete the opportunists and do not have to compete with the more sensitive species that are absent around platforms.

Main Conclusions

1. There is a clear correlation between benthic community disruption and hydrocarbon concentration in the sediments around platforms Alpha and Bravo; the number of individuals is highly correlated with total oil values, reflecting the increased numbers of individuals in the contaminated zones. Species abundance and diversity are negatively correlated with oil levels. This is the opposite of what is expected in an unstressed benthic community where increasing individual abundance usually results in more, not fewer, species. At platform Charlie, the number of species was positively correlated with the number of individuals.

   The observed distributions of sediment hydrocarbons and benthic fauna follows the general scheme proposed by Davies *et al.* (1984), who delineated the following four zones of effect associated with the discharge of cuttings contaminated with oil-base drilling muds in North Sea oil fields:

   (1) a zone where fauna are impoverished and benthic community structure is highly modified; hydrocarbon levels are over 100 times background, and sediments largely anaerobic (0 - 50 m);

   (2) a transition zone in benthic diversity and community structure; hydrocarbons 10 - 70 times background (200 - 4000 m);

   (3) a zone of no detectable benthic effects, but with hydrocarbons in sediments up to ten times background levels (800 - 4000 m);

   (4) a zone of no detectable effects of hydrocarbon contamination on benthos (beyond 4000 m).

2. The zone of effect was greater around Alpha than around Bravo and probably reflects the longer drilling history within the former field. Species numbers comparable to those in adjacent uncontaminated areas were reached 500-750 m from Bravo and 1000-1500 m from Alpha. Maximum values for diversity were also recorded at these distances.

3. At no time were abiotic conditions encountered at even the heavily contaminated sampling locations. In fact, the innermost stations around Alpha and Bravo supported extremely high numbers of individuals. Thus, the correlation between high hydrocarbon concentrations in sediments and biological change does not necessarily imply a toxic effect, and may simply reflect the effects of organic enrichment.

4. The primary cause of death of benthic fauna near the platforms was probably not due to the toxicity of hydrocarbons, but rather the physical effect of smothering by cuttings.

5. Comparison of the results of benthic studies conducted in 1980 and 1984 at Statfjord Alpha indicates that, although there has been considerable damage to the benthic fauna in the innermost zones (150-400 m) since 1980, the area of observable effects is still largely restricted to within 1000 m of the platform. In contrast, the diversity of the benthic fauna in regions 2500-3000 m away from the platform appears to have increased significantly since 1980, with higher numbers of both species and individuals being recorded in the 1984 survey.

6. The presence of a considerable biomass of benthic fauna in the zone of hydrocarbon contamination suggests that these species are using the hydrocarbons associated with the drill cuttings as a carbon source and may be degrading the petroleum hydrocarbons at a significant rate.

7. There are no observed differences in benthic communities near the Alpha and Bravo platforms that could be attributed to the type of drilling fluids used at these sites.

Experimental Studies

The Norwegian Institute for Water Research (NIVA) conducted a series of field experiments to investigate the suitability of different types and amounts of drill cuttings as a substrate for the support of benthic communities (Bakke et al. 1986a, b, c). The research involved deposition of a variety of materials in trays on the sea bottom for colonization by benthic organisms in such a way that the artificial substrates would be influenced by natural physical and chemical environmental factors. The experiment was completed in three phases.

Phase 1

The objectives of this phase were (A) to test the suitability of four types of discharged cuttings as substrates for the establishment of benthic organisms:

1. water-base mud cuttings;

2. low aromatic content oil-base mud cuttings;

3. diesel oil-base mud cuttings washed with diesel oil; and

4. diesel oil-base mud cuttings compressed into solid briquettes;

and (B) to study the chemical/biological degradation of the hydrocarbons on the cuttings over time. The experiment duration was 2 years and involved the use of 1-cm layers of the various drill cuttings as substrates for colonization by benthic fauna.

Phase 2

The objectives of this research phase were (1) to determine the thickness of cuttings required to alter the substrate sufficiently to delay or obstruct recolonization by benthic fauna, and (2) to determine if smothering or other physical or chemical effects were responsible for observed trends. Only two types of drill cuttings (low aromatic oil-base mud cuttings and diesel oil-base mud cuttings washed with diesel oil) were used in the Phase 2 studies, which extended for a period of one year. Variable thicknesses (0.5, 1, 3, 5 and 10 mm) of cuttings were used in the investigation.

Phase 3

This phase was designed to test the effects of cuttings contaminated with low aromatic base oil on mature benthic communities. This was accomplished by examining the response of a mature benthic community to exposure to a 0.5 mm thickness of oil-contaminated cuttings to determine whether tolerance to the cuttings could be linked to the ability of fauna to mix the pollutant with clean sediment through bioturbation. A community containing organisms with a high bioturbative potential is expected to be more tolerant of exposure to thin layers of cuttings than one with a low bioturbative potential.

Results and Conclusions of Phase 1

1. Within two weeks after the experimental substrates had been placed on the seafloor, the number of macrofauna species and individuals in the non-oiled substrates exceeded those associated with the oily substrates, which indicated that the oil-contaminated cuttings had a direct repellant effect on colonizers The difference in degree of recruitment of benthic fauna also increased with time.

2. Biological degradation of the oil (as indicated from the n-C_{17}/pristane, n-C_{18}/phytane and pristane/phytane ratios) was not observed during the first 12 months of exposure. However, after 15 months and particularly after 24 months, there was a decrease in the normal/branched alkane ratios, indicating that biodegradation of oil had occurred.

3. Two distinct patterns of community development were observed. The first corresponded to a "normal" succession pattern and was observed in the clean (non-oiled) substrates, while the other was a "pollution

type" succession that was evident in the oiled substrates. During the second year of the experiment, the benthic communities within the oiled substrates collapsed. It is believed that this mortality of fauna was mainly an indirect effect of the oil, specifically a reduction of redox potential within the substrate. The redox potential throughout the substrate trays were almost identical during the initial period of the experiment, but after 3 months, the oiled substrates became clearly more reducing (even at the surface). This condition may be explained by the formation of a water-impervious "lid" on the surface of the oiled substrate, which then prevented the transport of water and oxygen to the cuttings and substrate layer below. There was also no evidence that animals were able to penetrate this "lid".

4. The fauna that developed on the low aromatic cuttings during the first year of the experiment were somewhat better established than those associated with either the diesel oil or briquette cuttings. The difference among the oiled cuttings, however, were small compared to the differences in the communities between oiled and non-oiled cuttings, presumably due to the "lid effect" caused by the oiled cuttings. The slight improvement that was detected in the low aromatic cuttings substrate after one year disappeared during the second year when the benthic communities of the oiled substrates collapsed completely.

5. The applied cuttings layers acted as a complete physical barrier to the migration of burrowers into the underlying seabed sediment; the layers were undisturbed even after 30 months on the seafloor. The loss of bioturbators further decreases the ability of the substrate to support biota since less O_2 is mixed into the sediment as the number of bioturbators declines. The sediment becomes even less desirable for new benthic recruits, thereby restricting further the amount of O_2 which is mixed into the subsurface layers.

6. It appears that when the thickness of the oiled cuttings layer is approximately 1 cm or greater, the "lid" effect prevents establishment of benthic fauna. The acute toxicity of the oil associated with cuttings may have only a marginal incremental influence on fauna under these circumstances.

7. The total amounts of hydrocarbons in the oiled substrates were not significantly reduced over the 2-year experiment.

Results and Conclusions of Phase 2

1. No biological degradation of hydrocarbons was detected until after 3 months of exposure.

2. Benthic colonization was seriously affected by a 0.5-mm layer of low aromatic cuttings and 1-mm diesel oil cuttings layer. The largest improvement in community response occurred when the cuttings were completely removed. Among the substrates containing low aromatic cuttings, the largest improvement in the community response occurred when contamination was reduced from 3 mm to 1 mm, corresponding to a

change in total hydrocarbons from 26,000 mg kg^{-1} to 5000 kg^{-1} (dry weight basis). Among the diesel oil cuttings treatments, the greatest improvements occurred when contamination was reduced from 5 to 3 mm. This corresponded to a reduction in total hydrocarbons from 20,000 to 12,000 mg kg^{-1} (dry weight basis).

3. Since smothering of benthos is expected to be a minor source of impact with 0.5-mm and 1-mm layers of cuttings and because there was not evidence of a "lid" effect at these thicknesses, the effects of the thin layers of drill cuttings on the fauna were probably chemical, either the gradually more negative redox conditions or direct toxicity of associated hydrocarbons.

4. Overall, low aromatic cuttings appear to have less of an effect on benthic colonization than a comparable layer of diesel oil cuttings. Because the low aromatic cuttings contained 10 - 100% more hydrocarbons than the diesel oil cuttings, a large portion of the hydrocarbons in the low aromatic cuttings appeared to have no negative effects on the fauna.

Results and Conclusions of Phase 3

1. Exposure of two different benthic communities to a 0.2-mm layer of low aromatic cuttings (3000 - 4000 mg kg^{-1} total hydrocarbons) caused significant negative effects on the structure, bioturbation and respiration of these communities within three months.

2. There was no correlation between high bioturbative ability of organisms in a benthic community and high tolerance to cuttings contaminated with oil-base muds. Exactly the opposite trend was observed; the most bioturbative of the communities exposed to cuttings showed the most pronounced negative change in structure at the end of the experiment. This suggests that the major bioturbators present in the community had a high sensitivity to the oil on the cuttings. As a result, tolerance to drilling waste discharge may be more closely related to the species of bioturbators present in the community rather than the overall bioturbative potential of the community.

The Environmental Fate of Oil Adhering to Drill Cuttings

When oiled drill cuttings are discharged to the marine environment, their subsequent environmental fate is determined by a combination of physical, chemical and biological processes. The major biological process is biodegradation. The rate and extent of biodegradation is influenced by the inherent toxicity of the base oil in the cuttings, the mobility of the oil within the cuttings pile, the specific organisms comprising the local microbial populations, and the physical/chemical characteristics of the depositional environment where the cuttings accumulate. The nature and relative rates of biodegradation of oil on diesel base mud cuttings have been investigated in several laboratory and field experiments, as well as observed *in situ* during surveys around production facilities in the North Sea. The available results from these studies suggest that the ultimate fate and biodegradation of the oil adhering to drill cuttings is highly variable and not easily predicted *a priori*.

In field experiments conducted near the Loch Ewe Marine Station (Scotland), measured losses of straight chain alkanes suggested a much higher level of biodegradation in diesel mud cuttings than in "low toxicity" mud cuttings (Gillam et al. 1986). The result of laboratory experiments (Gillam et al. 1986) were consistent with the field observations. In tanks containing oil base mud cuttings overlying a clean sand substrate, a grey/white microbial mat became established on the diesel base mud cuttings but not on the low toxicity mud cuttings. This indicated that the diesel mud cuttings were more capable of supporting some form of biodegradation. The mat was shown to consist of a community of algae, protozoa and filamentous and unicellular bacteria. One particular organism isolated from the mat community and tentatively identified as Streptomyces sp. appeared to be twice as efficient in metabolism of diesel oil than it was at using low toxicity oils at concentrations less than 3% (v/v). This may be a reflection of the diverse potential carbon sources provided by the more complex diesel oil. In direct contrast to the above experimental results are the observations that: (1) benthic communities recovery rapidly (2-3 years) once the addition of low toxicity mud cuttings around a platform ceases (Sanders and Tibbetts 1986); and (2) given equal oil concentrations of diesel and low toxicity oil base drilling mud cuttings, diesel base cuttings are demonstrably more toxic to benthic fauna even after 400 days of weathering (Leaver et al. 1986).

The following general description of the fate and effects of diesel oil-base muds and low toxicity oil-base mud cuttings in the marine environment is based on information from studies conducted over the past few years. When cuttings containing oil-base drill mud enter the marine environment, the oxidative decomposition of the base oils exhausts the dissolved oxygen in the surface of the substrate and results in a decline in the redox potential. This leads to conditions suitable for the proliferation of sulphate-reducing bacteria which liberate H_2S, and thereby result in a further reduction in the redox potential. Free H_2S is highly toxic to most forms of marine life. It is believed that the toxicity of the free H_2S exceeds that of the toxic components of diesel oil (largely low molecular weight aromatics such as naphthalene). This would explain (1) the observations that diesel oil appears to degrade more rapidly than mineral oil during the initial period following disposal and (2) the appearance of a microbial mat on diesel-base mud cuttings, but not on the low toxicity base mud cuttings. With time, fresh oil migrates upward through the cuttings pile to the surface. Eventually, physical removal of the oil will overcome the supply from within the pile, and the production of H_2S associated with the low toxicity mud cuttings will decline, thereby resulting in a greater susceptability to biodegradation. At this point, the inherent toxicity of the base oils will probably determine the rate of biodegradation. Since diesel oil is much more toxic than mineral oil (LC50's 55 ppm and 10,000 ppm, respectively), the low toxicity mud cuttings will rapidly biodegrade. This is consistent with the observations that benthic recolonization in areas affected by mineral oil-base cuttings can occur within three years following cessation of discharges which is considerably more rapid that benthic recovery following exposure to diesel oil-base mud cuttings.

The differences in the rate of biodegradation of diesel and mineral base oils on drill cuttings naturally leads to questions regarding which of the following two options is environmentally preferable:

1. use of a base oil (diesel) that has a relatively low average rate of biodegradation, which results in a long residence time of toxic compounds in the marine environment, but does not lead to abiotic substrate conditions; or

2. use of a base oil (mineral) that, although inherently less toxic, can produce sediment conditions which are totally hostile to most forms of marine life (H_2S/reducing conditions) but are relatively short-lived.

The current consensus appears to favour the second option because it limits the potential for genetic changes and damage resulting from the long-term exposure of organisms to toxic compounds such as aromatic compounds found in diesel oil.

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PART 3:

HYPOTHESES AND PROJECT OVERVIEWS

INTRODUCTION

The following material describes all BEMP hypotheses and their linkages as they are currently envisaged. The current study has resulted in modification of linkages of Hypothesis 20: Oil-base Drilling Muds. All other hypotheses are the same as those reported in the 1984-1985 BEMP program.

Descriptions of current studies are included in this section of the report. Each program is described following the hypothesis to which it is most relevant. Some studies are relevant to more than one hypothesis, in which cases cross referencing has been used.

HYPOTHESIS NO. 1

SHIP TRAFFIC, SEISMIC EXPLORATION AND ACTIVE OFFSHORE STRUCTURES WILL CAUSE A REDUCTION IN THE WESTERN ARCTIC POPULATION OF BOWHEAD WHALES

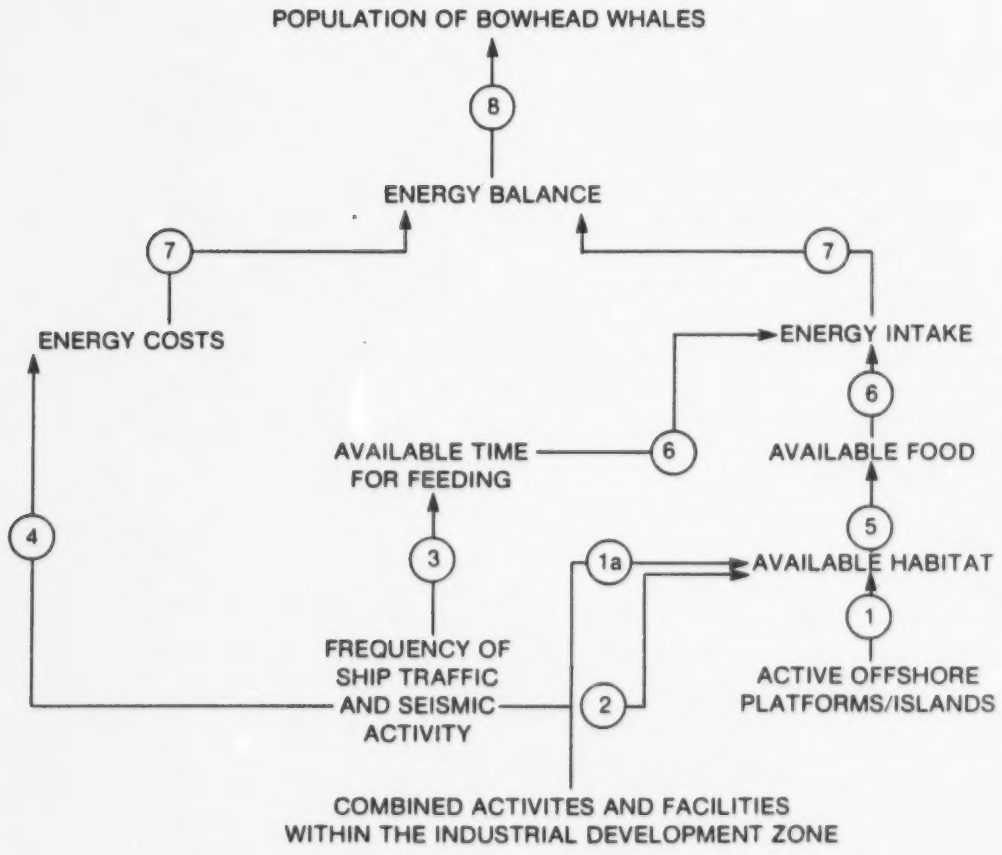
INTRODUCTION

As previously explained this hypothesis is an area of considerable interest and was the subject of a brief but intensive workshop in February 1986. The results, conclusions and recommendations of the workshop are described in Part 1. Since the hypothesis is a focus of interest, a considerable number of scientific studies and investigations have been conducted in 1985-86. Some of these are new projects but the majority are longer-term studies which have been described in previous BEMP reports. The following material describes 17 studies in considerable detail and explains their reference to the hypothesis.

FIGURE 1-1

POTENTIAL EFFECTS OF SHIP TRAFFIC, SEISMIC EXPLORATION AND ACTIVE OFFSHORE STRUCTURES ON BOWHEAD WHALES

Ship traffic, seismic exploration and active offshore structures will cause a reduction in the western Arctic population of bowhead whales



LINKAGES

1a. The cumulative effect of all offshore industry activities will be to create a large-scale zone of bowhead whale exclusion encompassing the entire industry zone.*

1. Each active offshore island or platform will exclude bowheads from a zone around the island/platform.

2. Ship traffic will exclude bowheads from a zone around the ship track.

3. Each passage of a ship will reduce the feeding time available to bowheads.

4. Each passage of a ship will increase the energy expenditure of whales due to avoidance behavior.

5. The available aquatic habitat determines the level of available food.

6. The amount of available food and the time available for feeding determine the energy intake.

7. Energy intake and expenditures determine the energy balance of a bowhead whale.

8. The energy balance of a bowhead whale determines its survival and its ability to reproduce.

* This hypothesis link was added to more clearly represent the emphasis on the cumulative impact of hydrocarbon development on bowhead whales.

BEMP PROJECT OVERVIEW NO. 1-1

TITLE:	1985 bowhead whale monitoring studies in the southeastern Beaufort Sea
PRINCIPAL INVESTIGATORS:	L. Harwood, J. Cubbage, G. Borstad, P. Norton
AFFILIATION:	Cascadia Research Collective, Olympia, WA.; G.A. Borstad Ltd., Sidney, B.C.; ESL Environmental Sciences Ltd., Sidney, B.C.; P.N. Research Projects, Sidney, B.C.
FUNDING SOURCE:	Environmental Studies Revolving Funds (ESRF)
EXPECTED COMPLETION DATE:	March 1986
RELEVANT BEMP HYPOTHESIS NUMBER(S):	1

BRIEF PROJECT DESCRIPTION

The 1985 bowhead whale monitoring program was the sixth consecutive year of systematic surveys of bowheads from mid-August to mid-September in their summer range in the southeast Beaufort Sea. The purpose of the study was to determine the relative distribution, abundance and age segregation of bowheads in relation to oil industry activities and oceanographic features in the region. The study area for the systematic surveys extended from 141°W longitude (Yukon-Alaska border) to 127°W longitude (near Cape Bathurst), and from the 2 m isobath seaward. The planned northern boundary of the study area was 25 km beyond the 100 m isobath, except between 141°W and 138°W longitude where the boundary was planned to be 70°20'N latitude. However, the ice cover in the Beaufort during 1985 was more extensive than in past years and, therefore, the actual northern boundary of most transect lines was 16 km beyond the start of 9+/10 ice cover. The methods followed during the surveys were consistent with those used in previous years, and included a minimum of 10% survey coverage throughout the study area and observations of other marine mammals in the region.

As in 1984, the present bowhead program also included a coincident satellite imagery component to allow comparison of bowhead distribution patterns with oceanographic features (surface sea temperature, water colour) depicted in imagery. The satellite data were relayed to the field crew on a near real-time basis. The 1985 program also included a photographic component which involved the use of a second survey aircraft and crew. The objectives of the latter component were to obtain data on the age (size) distribution of bowheads in different parts of the study area, as well as photogrammetric information that would allow re-identification of whales.

During both the August and September surveys, most bowheads were observed offshore from the Yukon coast, and few whales were recorded off the Mackenzie Delta or Tuktoyaktuk Peninsula. In August, the majority of the bowheads off the Yukon coast were 10-45 km offshore, while a larger proportion of whales was found within 10 km of the coast during the September surveys. Observations of whales suggested that only small-scale movements were occurring and that fall migration did not begin until after the mid-September survey. The final report for this study will compare spatial

distribution patterns observed in 1985 with trends noted during the previous five years of systematic aerial surveys. The distribution and abundance of bowheads in relation to oil industry activities and oceanographic features (e.g., thermal fronts associated with ice edge, river plume and upwelling phenomena) will also be examined in detail and contrasted with observations from previous years. The data analysis for this project has not been entirely completed. Nevertheless, the association of bowheads with frontal features such as the plume edge, as seen in 1984, was also documented this year. There was also evidence that upwelling may have been occurring in the vicinity of large congregations of bowheads along the Yukon coast at Kay, King and Shingle points.

The use of an onboard microcomputer interfaced to the aircraft navigation system and radar altimeter greatly increased the precision and accuracy of the aerial photography over that used in past photogrammetric programs in the Canadian and Alaskan portions of the Beaufort Sea. The length frequency distribution of bowheads in the study area was found to be skewed towards yearlings and subadults, and could not represent the length distribution of the entire population. Only 11% of the animals photographed were adults, and the two largest animals photographed were in an area off Atkinson Point.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

Although the systematic aerial surveys of bowhead whales in the Beaufort Sea have occurred each year since 1980, the design of programs conducted in the past two summers has been a direct result of recommendations made during the first and second years of BEMP. The research is relevant to Hypothesis No. 1, which states that "Ship traffic, seismic exploration and active offshore structures will cause a reduction in the western Arctic population of bowhead whales". The long-term database that is resulting from this (and other) bowhead research programs will contain some of the information necessary to distinguish potential effects of oil industry operations from within-season and yearly changes in distribution patterns associated with natural factors. The results of the 1985 bowhead whale studies provide further evidence that the spatial distribution of at least some component of bowhead population may be a reflection of regional and local variations in food (zooplankton) availability, since bowheads were most commonly observed in areas where convergence phenomena at frontal features may concentrate planktonic organisms. However, the reason for the limited numbers of mature bowheads in the study area, particularly off the Yukon coast, remains unknown.

BEMP PROJECT OVERVIEW NO. 1-2

TITLE:	Factors determining bowhead whale distribution in the Beaufort Sea: a feasibility study
PRINCIPAL INVESTIGATORS:	D. Thomson, R. Davis, D. Fissel, J. Marko and G. Borstad
AFFILIATION:	LGL Limited, King City, Ontario; Arctic Sciences Ltd., Sidney, B.C.
FUNDING SOURCE:	ESRF
EXPECTED COMPLETION DATE:	January 1986
RELEVANT BEMP HYPOTHESIS NUMBER(S):	1

BRIEF PROJECT DESCRIPTION

This study was reported in 1985 (1985 BEMP Project Overview No. 2) and the final results are now available.

Between 1980 and 1983, systematic aerial surveys of the distribution of bowhead whales over their summer range were conducted in the southeastern Beaufort Sea. During this four-year period, there have been fewer animals occurring in the zone where activities of the petroleum industry have been concentrated.

Two interrelated hypotheses were advanced during Phase 1 of BEMP to explain the differences in bowhead whale distribution in the period from 1980 and 1983. These were:

1. bowheads will avoid the industrial zone because of noise and disturbance in this region of the Beaufort Sea; and

2. bowhead distribution is determined by the locations of available food (areas containing relatively high zooplankton densities).

On the latter point, the distribution of zooplankton patches is expected to be related to oceanographic and meteorological factors.

The objective of the feasibility study was to evaluate the feasibility of using simply (and inexpensively) measured environmental data (i.e., wind, surface distribution of sea temperature and turbidity obtained from satellite imagery) to predict bowhead distributions. To meet this objective the available environmental data from 1980-83 were examined to determine the locations of potential zooplankton concentrating mechanisms (as indicated by surface oceanographic features). These data were compared with bowhead distributions within the same period to determine whether or not the distributions of bowheads are correlated with environmental data.

Wind and Mackenzie River discharge data for the months of July, August and September in 1980-1983 were collected and grouped into periods that defined specific wind events. All available satellite imagery for these periods was analysed, using both the visible and thermal bands to map locations of the boundaries of the Mackenzie River plume. Available data on bowhead whale distributions were also mapped by wind event periods.

Analysis of the small amount of zooplankton data that has been collected in the eastern Beaufort indicated that zooplankton standing stock was positively correlated with salinity. This suggests that areas covered by the low salinity portions of the Mackenzie River plume may support low densities of zooplankton, and therefore would not be suitable feeding habitats for bowhead whales. The area where industrial activities have been focused lies within a transition zone that, depending on the winds, may or may not be under the influence of this concentrated plume. During periods when the wind is from the west, the plume tends to be situated along the shore of the Tuktoyaktuk Peninsula and Richards Island. During easterly winds, the majority of the industrial zone north and west of Richards Island is more greatly influenced by estuarine water.

During 1980, bowhead whales were found off Richards Island during the first part of August, and the highest densities of whales were observed to the northeast of Richards Island during successive weeks. An estuarine front was also transported successively to the northeast throughout this period, and the locations of bowheads closely corresponded to the locations of these fronts.

In 1981, bowhead whales were not found in the industrial zone until the latter part of August. During the first part of August, this area was characterized by a surface layer of low salinity water, and the subsequent appearance of whales was accompanied by an increase in salinity. In contrast, the salinity was high in the industrial zone throughout the 1980 open water season.

Whales were not abundant in the industrial zone in 1982 and 1983. A comparison of wind regimes, temperature data and satellite imagery with the presence or absence of whales in this zone suggests the following:

1. there were periods in 1982 and 1983 when whales would have been expected to be present on the basis of the 1980 and 1981 wind and oceanographic conditions and the concurrent presence of large numbers of whales;

2. the presence of whales in the industrial zone was associated with a strong northerly component to the wind; and

3. the absence of whales from the industrial zone was associated with a lack of this northerly wind component.

Results of this research program suggest that the presence of bowhead whales in the industrial zone is associated with the presence of high salinity waters and, on some occasions, the presence of estuarine fronts. However, the whales are not always present in areas of high salinity or near fronts.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

Hypothesis No. 1 states that 'Ship traffic, seismic exploration and active offshore structures will cause a reduction in the Western Arctic population of bowhead whales'. This ESRF-funded study is examining an interrelated hypothesis: bowhead whale distribution patterns are related to

oceanographic factors which influence the distribution of the food supply of this population. The research program is relevant to BEMP because it will provide information on oceanographic factors that may directly and indirectly influence the distribution of bowhead whales. The validity of Hypothesis No. 1 would be significantly reduced if evidence in support of this interrelated hypothesis emerges from the bowhead whale feasibility study and/or subsequent field research programs.

BEMP PROJECT OVERVIEW NO. 1-3

TITLE:	Importance of the eastern Alaskan Beaufort Sea to feeding bowheads
PRINCIPAL INVESTIGATOR:	W. John Richardson
AFFILIATION:	LGL Ltd., King City, Ontario
FUNDING SOURCE:	U.S. Minerals Management Service
EXPECTED COMPLETION DATE:	1987
RELEVANT BEMP HYPOTHESIS NUMBER(S):	1, also of general interest

BRIEF PROJECT DESCRIPTION

Most individuals of the western Arctic population of bowhead whales spend the period from May or June to September or October in the Beaufort Sea. During this period they are believed to consume most of the food needed for the entire year. Bowheads, like other baleen whales, are believed to consume little food in winter, although this point is not proven in the case of bowheads. In any case, the Beaufort Sea is clearly of critical importance in the annual energy budget of the great majority of the Western Arctic bowheads.

The general purpose of this two-year project is to quantify what proportion of the energy requirements of the Western Arctic bowhead whale stock is provided by food resources located in the eastern Alaskan Beaufort Sea. The study area for this project is the eastern part of the Alaskan Beaufort Sea, from longitude 144°W east to the eastern edge of the zone whose jurisdiction is in dispute between the U.S.A. and Canada. The study area extends from the coast of northeastern Alaska north to latitude 71°30'N.

The main factors that have to be considered in achieving the objectives of the study are:

1. the numbers, activities and residence times of bowhead whales in the area;

2. prey identity, availability, distribution, patchiness and energy content, and oceanographic factors controlling these attributes of the prey;

3. amount of prey (and of energy) consumed by the various categories of bowheads that may feed in the study area (immatures, adult males and females, etc.); and

4. total energy needs of individual bowheads and of the population of bowheads.

The 1985 and 1986 field programs involve two main tasks: (1) studies of zooplankton and the physical and biological processes that affect zooplankton; and (2) studies of the utilization of the eastern Alaskan Beaufort Sea by bowhead whales. Each of these tasks includes a variety of subtasks. In 1985, studies of zooplankton and their supporting processes

included:

1. hydroacoustic surveys to determine zooplankton distribution and relative biomass in various areas and positions in the water column;

2. net sampling at selected stations and depths to determine actual numbers, biomass and species composition, and to provide zooplankton samples for size-frequency, calorimetry, and other analyses;

3. boat-based measurements of water temperature, salinity, and chlorophyll content;

4. aerial remote sensing of water temperature, chlorophyll and sediment content on a near-synoptic basis; and

5. digital processing of satellite imagery to acquire synoptic data on sea surface temperature and water colour on the few cloud-free days.

Studies of bowhead whales in 1985 included:

1. aerial and boat surveys of distribution, numbers, and movements;

2. observations of feeding behavior and other activities; and

3. photogrammetric work to study population composition and recurrence of identifiable individuals in feeding areas.

RELATIONSHIP AND RELEVANCE TO BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This project is of greatest relevance to Hypothesis 1, 'Ship traffic, seismic exploration and Active offshore structures will cause a reduction in the western Arctic population of bowhead whales', but is also of relevance to other hypotheses concerned with trophic relationships since it provides data on the amount and distribution of planktonic food available in the Beaufort Sea. The study will provide information relevant to the assessment of the two hypotheses attempting to explain the small numbers of bowheads seen in the industrial area since 1980. These hypotheses are (1) bowheads have been excluded by disturbance from the industrial area, and (2) bowhead distribution is controlled by oceanographic factors which influence the distribution of food. The present study is designed to determine whether bowheads feed preferentially in areas where density of plankton is high and it is also designed to determine whether such areas are identifiable by physical means. If it is shown that bowheads do feed preferentially where plankton density is high, then this would lend credence to the hypothesis that bowhead distribution is controlled by oceanographic factors affecting the availability of food. If easily measured oceanic factors are highly correlated with food abundance, this would assist regulatory agencies in making defensible decisions about permitted industry activities in potential bowhead feeding areas.

BEMP PROJECT OVERVIEW NO. 1-4

TITLE:	Food availability characteristics of the offshore Yukon coast to the bowhead whale
PRINCIPAL INVESTIGATOR:	Michael Bradstreet
AFFILIATION:	LGL Ltd., King City, Ontario
FUNDING SOURCE:	INAC, NOGAP
EXPECTED COMPLETION DATE:	1986
RELEVANT BEMP HYPOTHESIS NUMBER(S):	1, and of general interest

BRIEF PROJECT DESCRIPTION

The primary objective of this study is to gain a better understanding of the importance of the Yukon nearshore and adjacent marine areas in the annual energy budget of the bowhead whale. Data collection techniques include sampling of zooplankton by means of both oblique and surface bongo net tows, hydroacoustic sampling to assess the extent of zooplankton patches, and collection of physical oceanographic data both by satellite and directly.

In 1985, zooplankton samples were collected at five stations along each of five transects running perpendicular to shore between Sabine Pt. and Collinson Head, Herschel Island. Sampling stations were located at the 5 m and 10 m depth contours and at 5, 10 and 15 n mi (9.3, 18.5, and 27.8 km) offshore. In addition to the samples taken in this grid, horizontal bongo tows were made in areas where the echosounder indicated zooplankton patches and also, on one occasion, when feeding bowheads were encountered off Kay Pt. On this occasion samples were taken in the area where the bowheads were feeding and in a nearby area where feeding was not occurring.

The quantity of material collected was quite large at some stations, especially near shore and near feeding bowheads. Samples consisted mainly of copepods, with very large numbers of small copepods being taken. Y-O-Y Arctic cod, pteropods, mysids, amphipods, hydrozoans, chaetognaths and euphausiids were also taken in the samples.

RELATIONSHIP AND RELEVANCE TO BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This project will provide data similar to those from the previous project (BEMP Project Overview No. 1-3) but for areas in the Canadian Beaufort Sea. The project is of greatest relevance to Hypothesis 1, but is also of relevance to other hypotheses concerned with trophic relationships since it provides data on the amount and distribution of planktonic food available in the Beaufort Sea.

BEMP PROJECT OVERVIEW NO. 1-5

TITLE:	Reproductive parameters of the bowhead whale and the status of the western Arctic bowhead population
PRINCIPAL INVESTIGATORS:	R. Davis, P. McLaren, W. Koski
AFFILIATION:	LGL Ltd., King City, Ontario
FUNDING SOURCE:	Sohio Alaska Petroleum Co. and other Alaskan industry sources
EXPECTED COMPLETION DATE:	1986
RELEVANT BEMP HYPOTHESIS NUMBER(S):	1

BRIEF PROJECT DESCRIPTION

The objectives of this study are:

1. Estimation of Gross Annual Recruitment Rate (GARR), defined as the number of calves as a proportion of the population, for the western Arctic stock of bowheads;

2. Estimation of the proportion of yearlings in the population;

3. Assessment of geographic segregation of age classes on summer range;

4. Assessment of geographic segregation of animals of different reproductive status on summer range; and

5. Estimation of calving interval.

The study was conducted by means of extensive systematic aerial surveys in both Amundsen Gulf and the Beaufort Sea. Bowheads were photographed whenever they were encountered with the objective of photographing as large a proportion of the population, and especially the adult population, as possible. Age classes will be assessed through length measurements, and it is hoped that calving interval can be estimated through repeat identifications of females photographed with calves in previous years.

RELATIONSHIP AND RELEVANCE TO BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This project is directly relevant to Hypothesis 1, 'Ship traffic, seismic exploration and active offshore structures will cause a reduction in the western Arctic population of bowhead whales'. Estimates of the reproductive rate of this population have been made during studies designed for other purposes and have varied considerably. This is the first study designed specifically to determine reproductive rate.

The summer range of bowheads in the Beaufort Sea has varied considerably from year to year but the factors controlling distribution remain unknown. Few bowheads have been seen in the industrial zone since 1980 and it has been postulated that they have been excluded from an important feeding area by disturbance from industrial activities. Alternatively, oceanographic

influences on food resources may be the factor affecting bowhead distribution. If it is shown that the population is healthy and growing even though the industrial area has not been used for 5 years then the validity of Hypothesis 1 is reduced. Conversely, if the reproductive rate is found to be low, serious concerns remain that exclusion from the industrial area may be affecting the population.

BEMP PROJECT OVERVIEW NO. 1-6

TITLE:	Bowhead migration monitoring
PRINCIPAL INVESTIGATORS:	R. Davis, P. McLaren
AFFILIATION:	LGL Ltd., King City, Ontario
FUNDING SOURCE:	Union Oil Co.
EXPECTED COMPLETION DATE:	1986
RELEVANT BEMP HYPOTHESIS NUMBER(S):	1

BRIEF PROJECT DESCRIPTION

Aerial surveys were conducted in the Alaskan Beaufort Sea from 5 September to 20 October 1985 in the approximate area of 145°W to 147°W. The objective of the study was to determine the distribution and behaviour of bowheads near an inactive drillsite during fall migration.

RELATIONSHIP AND RELEVANCE TO BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This study provides background information about timing of bowhead whale movements that is relevant to Hypothesis 1.

BEMP PROJECT OVERVIEW NO. 1-7

TITLE:	Bowhead migration monitoring
PRINCIPAL INVESTIGATORS:	R. Davis, S.R. Johnson
AFFILIATION:	LGL Ltd., King City, Ontario
FUNDING SOURCE:	Shell Western E&P
EXPECTED COMPLETION DATE:	1986
RELEVANT BEMP HYPOTHESIS NUMBER(S):	1

BRIEF PROJECT DESCRIPTION

Aerial surveys were conducted from 13 September to 20 October 1985 to monitor bowhead migration in the area between 147°30'W and 149°30'W. The objective of the study was to monitor bowhead movements and distribution near an artificial island during fall migration.

RELATIONSHIP AND RELEVANCE TO BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This study provides background information about timing of bowhead whale movements that is relevant to Hypothesis 1.

BEMP PROJECT OVERVIEW NO. 1-8

TITLE:	Bowhead migration monitoring
PRINCIPAL INVESTIGATORS:	C. Holdsworth, W.G. Alliston
AFFILIATION:	LGL Ltd., King City, Ontario
FUNDING SOURCE:	Shell Western E&P
EXPECTED COMPLETION DATE:	1986
RELEVANT BEMP HYPOTHESIS NUMBER(S):	1

BRIEF PROJECT DESCRIPTION

Aerial surveys were conducted from 7 to 18 October 1985 to determine how late in the season bowheads remained in the Canadian Beaufort Sea.

RELATIONSHIP AND RELEVANCE TO BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This study provides information that is relevant, at least by inference, to Links 3 and 6 of Hypothesis 1. These links suggest that the energy intake of bowheads will be reduced because bowheads lose feeding time when avoiding ships. Bowheads of the western Arctic stock are believed to obtain most of their yearly energy requirements while feeding in the Beaufort Sea and particularly the Canadian Beaufort Sea. The significance of loss of feeding time can only be assessed if time available for feeding is known. This study provides information relating to the length of time that at least some bowheads in some years remain in potential feeding areas.

BEMP PROJECT OVERVIEW NO. 1-9

TITLE:	Relationship between bowhead whale distribution during fall migration and surface oceanography of northern seas as seen by satellite imagery
PRINCIPAL INVESTIGATOR:	Gary Borstad
AFFILIATION:	G.A. Borstad Ltd., Sidney, B.C.
FUNDING SOURCE:	Shell Oil
EXPECTED COMPLETION DATE:	July 1986
RELEVANT BEMP HYPOTHESIS NUMBER(S):	1

BRIEF PROJECT DESCRIPTION

The main portion of the work for this study will not begin until March 1986. The objectives of the study are similar to one of the objectives of the 'feasibility study' conducted in the Canadian Beaufort Sea (BEMP Project Overview No. 1-2), that is, to assess whether oceanographic features visible on satellite imagery can be consistently correlated with bowhead distribution. For the present study, the period of interest is fall migration. The areas that will be assessed include Amundsen Gulf, the Alaskan Beaufort Sea and the Chukchi Sea. Data on bowhead distribution are available for 1979 to 1985. Special efforts will be made to correlate observations of feeding whales with oceanographic features.

RELATIONSHIP AND RELEVANCE TO BEAUFORT ENVIRONMENTAL MONITORING PROJECT

It was noted in BEMP Project Overview No. 1-2 (Factors determining bowhead whale distribution in the Beaufort Sea: A feasibility study) that the validity of Hypothesis 1 would be significantly reduced if it were shown that bowhead whale distribution patterns are related to oceanographic factors that influence the distribution of the food supply of the population. Although that study, conducted in the Canadian Beaufort Sea, was unable to show conclusively that bowhead summer distribution is controlled by oceanographic features, the use of satellite imagery remains a promising technique. If bowhead distribution can be shown to be correlated with oceanographic features during migration, this would support the hypothesis that summer distribution is also influenced by oceanographic features.

BEMP PROJECT OVERVIEW NO. 1-10

TITLE:	Assessment of the two-stock hypothesis via commercial whaling records
PRINCIPAL INVESTIGATORS:	M. Fraker, J. Bockstoce, D. Botkin
AFFILIATION:	Sohio Alaska Petroleum Co. University of California
FUNDING SOURCE:	Sohio Alaska Petroleum Co. and other Alaskan industry sources
EXPECTED COMPLETION DATE:	July 1986
RELEVANT BEMP HYPOTHESIS NUMBER(S):	1, 6

BRIEF PROJECT DESCRIPTION

Commercial whalers took many bowheads in the Bering and Chukchi seas in summer but few or no bowheads summer in these areas today. Bowheads did summer in the Canadian Beaufort Sea, as they do today, during the commercial whaling period. These observations suggest that there may have been two stocks of bowheads in the western Arctic, one that formerly summered in the Bering and Chukchi seas and may be extinct, and one that still summers in the Beaufort Sea. This study will attempt to address the 'two-stock hypothesis' through analysis of the records from the commercial whaling era. The study will also attempt to estimate the initial number of bowheads in each stock if, indeed, there appear to have been two stocks.

RELATIONSHIP AND RELEVANCE TO BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This study is relevant to all hypotheses that include consideration of food chains. If there were, indeed, two stocks of bowheads in the mid-1800's, it is possible that the numbers of bowheads that feed in the Beaufort Sea today are closer than generally believed to the numbers that fed there in historical times. Thus, changes in availability of food for other species, because of reduced competition from bowheads, may not be as great as has been postulated.

BEMP PROJECT OVERVIEW NO. 1-11

TITLE:	Historical variability of bowhead summer distribution
PRINCIPAL INVESTIGATORS:	M. Fraker, J. Bockstoce, D. Botkin
AFFILIATION:	Sohio Alaska Petroluem Co. University of California
FUNDING SOURCE:	Sohio Alaska Petroleum Co. and other Alaskan industry sources
EXPECTED COMPLETION DATE:	July 1986
RELEVANT BEMP HYPOTHESIS NUMBER(S):	1

BRIEF PROJECT DESCRIPTION

Summer distribution of bowheads in the eastern Beaufort Sea has varied considerably from year to year during the past decade. This study will use historical whaling records, and estimates of catch/unit effort obtained from these records, in an attempt to determine whether similar variations in summer distribution occurred during the commercial whaling period.

RELATIONSHIP AND RELEVANCE TO BEAUFORT ENVIRONMENTAL MONITORING PROJECT

The observed reduction in the numbers of bowheads occurring in the industrial zone of the Beaufort Sea during 1980-85 has led to the suggestion that bowheads have been excluded from traditional summering areas by disturbance from industrial activities. Alternatively, it has also been suggested that the variability in distribution of bowheads is due to variations in oceanographic features that control the distribution of the food required by the whales. Demonstration that distribution during the whaling period was as variable from year to year as it is today would provide support for the second hypothesis.

BEMP PROJECT OVERVIEW NO. 1-12

TITLE:	Feasibility of tagging bowhead whales for tracking by satellite
PRINCIPAL INVESTIGATOR:	Bruce Mate
AFFILIATION:	Marine Science Center, Oregon State University
FUNDING SOURCE:	U.S. Minerals Management Service
EXPECTED COMPLETION DATE:	Unknown
RELEVANT BEMP HYPOTHESIS NUMBER(S):	1

BRIEF PROJECT DESCRIPTION

This study has been ongoing on various species of whales since 1979. Initially, conventional radio-tagging was successfully tested on gray whales. In 1983 a satellite transmitter was attached to a humpback whale and remained in place for 6 days while the whale travelled 1000 km. Subsequently, two gray whales were tagged in the winter of 1984 but the transmitters remained in place for only two days. In the summer of 1986 gray whales will be tagged again and, if one of three tags remains in place for at least two months, then attempts will be made to tag bowheads in fall, 1986. If the tests on gray whales are once again unsuccessful, the project will be abandoned.

Attachment of the transmitters has been accomplished to date from specially rigged Zodiacs. However, tests are ongoing with a radio-controlled model helicopter.

RELATIONSHIP AND RELEVANCE TO BEAUFORT ENVIRONMENTAL MONITORING PROJECT

The ability to track individual bowheads for long periods of time would add considerably to knowledge of whale movements in the Beaufort Sea and, in particular, may allow assessment of individual variation in responsiveness to disturbance from industrial sources (Hypothesis 1).

BEMP PROJECT OVERVIEW NO. 1-13

TITLE:	The long-term effects of offshore industrial activities.
PRINCIPAL INVESTIGATOR:	Rolph Davis
AFFILIATION:	LGL Limited, King City, Ontario
FUNDING SOURCE:	DSS, NOGAP (DIAND and DFO)
EXPECTED COMPLETION DATE:	1986
RELEVANT BEMP HYPOTHESIS NUMBER(S):	1

BRIEF PROJECT DESCRIPTION

The purpose of this study was to test the application of a photographic identification technique in the examination of medium- and long-term responses of bowhead whales to offshore industrial development. A photographic method of identifying recognizable bowheads has proven effective in that resightings of specific individuals have been documented. In this study, the technique was used to document the occurrence and duration of stay of bowhead whales near industrial sites and elsewhere in the southeastern Beaufort Sea.

The study area included the offshore hydrocarbon exploration areas of the Mackenzie Delta and Tuktoyaktuk Peninsula, and extended west to Herschel Island and east to Franklin Bay. Within this region, areas of most intensive study were determined by the concentrations of whales.

Emphasis was placed on repeated searches to determine whether recognizable individuals were resighted at similar rates in areas of industrial activity and in unaffected control areas. Although results obtained during the 1984 open-water season are discussed in greatest detail, data on identifiable whales obtained in 1981-83 studies (LGL, NMFS) allowed some determination of year-to-year recurrence rates. The photographic technique also permitted determination of the size and status (i.e., calf, yearling, immature, mature) of individual whales, and indicated whether or not the whales occurring near industrial activities were a random segment of the population. The research also involved detailed observation of bowhead behaviour patterns.

The study was co-ordinated with LGL's study of the short-term behavioural reactions of bowhead whales to industrial activities (1985 BEMP Project Overview No. 37).

The principal findings of this study of this study that are relevant to Hypothesis No. 1 are summarized below.

1. The numbers of bowheads found in the offshore industrial zone during August and early September 1984 were somewhat greater than in 1982 and 1983, but were still substantially lower than numbers observed in 1980 and 1981.

2. Congregations of whales that persisted along the Yukon Coast and along the plume edge northeast of Shingle Point consisted primarily of small animals. These bowheads were exposed to varying degrees of industry-related noise and disturbance. A few larger animals were occasionally present in these areas, but were only briefly observed

and apparently did not remain in the zone. From this and previous photogrammetric studies of bowhead whale size/frequency, the authors concluded that the small animals referred to above were probably yearlings and other immature age classes, while the larger animals were adults and near-adults.

3. Most bowheads in the southern part of the main industrial zone off the Mackenzie Delta were also small. Information on residence times also suggests that these animals moved through the area relatively quickly.

4. Large animals, which were probably adults and sub-adults, were found primarily outside the industrial zone in Franklin Bay and the northern edge of the industrial zone.

These findings indicate that for the third consecutive year, relatively few bowheads were present in the industrial zone. Those individuals that were present were mostly small young animals. The older component of the population apparently did not occur in the development zone.

As evident in some other whales species, this trend may be a result of differential feeding and/or habitat requirements of various age (and/or sex) classes of the population. The author raised the concern, however, that since there is presumably a relationship between age (as estimated from size) and experience, the apparent differential distribution could indicate that there is a general learned avoidance of the industrial zone by bowhead whales.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

Hypothesis No. 1 states that 'Ship traffic, seismic exploration and active offshore structures will cause a reduction in the western Arctic population of bowhead whales'. More specifically, active drilling or production islands have associated ship and helicopter traffic, and these mobile noise sources could act in conjunction with on-island activities to produce a zone of at least partial exclusion of whales around offshore islands and platforms.

During 1980 and to a lesser extent 1981, large numbers of bowheads occurred within the industrial zone of the Beaufort Sea. In contrast, very few bowheads occurred in this zone during the summers of 1982 and 1983. The 1983-84 BEMP report suggested that these variations in bowhead distribution may be related to variations in food (zooplankton) distribution and availability, which are in turn influenced by both regional and local oceanographic phenomena. Initial assessment of information relevant to this hypothesis is being conducted as part of an ESRF study described earlier (see BEMP Project Overview No. 2). The alternate hypothesis is that changes in whale distribution from 1980-83 may be due to industrial disturbance and displacement of animals. The present study (in concert with the U.S. MMS Behaviour Study, 1985 BEMP Project Overview No. 37) examined this hypothesis by attempting to document the medium- and long-term behavioural responses of bowheads to industrial activities. In contrast to the BLM study of short-term changes in behaviour (several hours), this program involved study of the movements and behaviour of individual animals over a period of days or weeks.

BEMP PROJECT OVERVIEW NO. 1-14

TITLE:	Assessment of the value of stratified sampling for aerial surveys; a case study of bowhead whales in the Beaufort Sea
PRINCIPAL INVESTIGATORS:	E. Oguss, I. Robertson
AFFILIATION:	Ian Robertson Consulting Ltd.
FUNDING SOURCE:	DFO
EXPECTED COMPLETION DATE:	Complete
RELEVANT BEMP HYPOTHESIS NUMBER(S):	1, and of general interest

BRIEF PROJECT DESCRIPTION

The purpose of this study was to re-examine existing bowhead whale survey data from the Beaufort Sea to assess (1) whether stratification of the study area would enhance population estimates and (2) whether redistribution of sampling effort would be wise.

Data from 1981 to 1984, based primarily on observations made during aerial surveys of equally spaced (i.e., systematic) transects, were examined. The data included exact locations of whale sightings and these locations were used to regroup the data so that all sightings fell into 110 subareas defined by latitude and longitude boundaries. The relative density of whales observed in each subarea was then ranked for all eight (two in each year) surveys. Pairs of contiguous subareas were then grouped hierarchically to define strata. In this study, division of the surveyed area into 10, 5, 3, and 2 strata was examined.

Stratification into 10, 5 or 3 subareas was not useful because the locations of the strata were too variable from year to year. Stratification using only a high density and a low density stratum resulted in moderately stable stratum boundaries but boundaries were still sufficiently unstable that the authors concluded that it would be unwise to make major changes in sampling effort based on data from previous years.

The regrouped data were also used to assess effects of migratory movements and group size on estimates of numbers. It was concluded that neither factor likely affected previous estimates of numbers.

The authors of this study recommend that surveys for bowheads continue to be collected by means of systematic transects but that the data subsequently be regrouped into smaller units for analysis. Their reasoning for this recommendation included the following considerations:

1. transect surveys are easier to conduct given the difficult logistics of arctic surveys;

2. square subareas are more likely than transects to be homogeneous with respect to both environmental factors and whale density;

3. use of subareas makes it easier to deal with unusual situations such as the occasional large group or the occasional area with intensive survey coverage; and

4. more time can be spent in high density areas with relatively low risk of biasing density estimates in low density areas.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This study has implications for the analysis of aerial survey data that are relevant to estimation of populations of any species that might be surveyed from the air. The study has particular implications, however, for Hypothesis 1. Because of the endangered status of the bowhead, it is particularly important that estimates of numbers be as precise as possible. Precise estimates are particularly important when distribution is used as an indicator of attraction to or avoidance of, for example, oceanographic features or industrial activity.

BEMP PROJECT OVERVIEW NO. 1-15

TITLE:	Marine mammal remote sensing techniques
PRINCIPAL INVESTIGATORS:	G. Yaremchuk
AFFILIATION:	Fisheries and Oceans Canada, Freshwater Institute
FUNDING SOURCE:	PERD, NOGAP, DFO, World Wildlife Fund
EXPECTED COMPLETION DATE:	1989
RELEVANT BEMP HYPOTHESIS NUMBER(S):	1 to 5

BRIEF PROJECT DESCRIPTION

This umbrella project encompasses several subprojects that are described elsewhere in this report (BEMP Project Overview No.'s 2-4 and 3-6) or in the 1985 BEMP report (1985 BEMP Project Overview No. 15). The project has three major long-term objectives:

1. to develop optimal photographic survey techniques for monitoring the distribution, abundance and age structure of marine mammal populations in the vicinity of arctic offshore hydrocarbon activities;

2. to investigate the use of airborne infra-red sensors for monitoring of marine mammal distribution and abundance during seasons when they cannot be monitored by visual or photographic techniques; and

3. to investigate the relationships between arctic marine mammal distributions and oceanographic parameters such as temperature, interaction of water masses, and ocean colour through aerial surveys and the collection of oceanographic data using airborne and satellite-borne sensors. It is hoped that such data will permit identification of critical habitat and indirect determination of marine mammal distributions. It is also hoped that these data will permit changes in distributions caused by changes in these parameters to be distinguished from changes due to avoidance of industrial activity.

In 1985 about 100 h of surveys using a low-light video camera, FLIR thermal infra-red video scanner and Wilde RC8 metric aerial survey camera were used to collect information about narwhal distribution and abundance, ice cover, thermal oceanographic features and water colour. Initial analysis suggested a strong association between narwhals and thermal oceanographic features believed to represent upwellings.

Transects were also flown at intervals between 500 and 5000 ft to test the ability of the sensors to detect animals. Identification of narwhals and belugas to maturity class was possible from RC8 imagery taken at 5000 ft, 2000 ft higher than on previous surveys. The increased coverage resulting from the higher altitude will greatly decrease the cost of future surveys. Narwhals and belugas could be detected on low-light video recordings made at altitudes of 5000 ft. Identification to species was possible to at least 1500 ft. The bow waves, wakes and possibly blows of whales could also be detected.

During the next three years of the project, work will continue on the narwhal monitoring project described above and additional work will be done on the infra-red detection of seal lairs. Projects to be initiated include attempts to estimate population statistics using aerial photography and attempts to monitor winter distribution of marine mammals through infra-red and low-light video cameras.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

The results of the studies conducted under this overall project will have direct application to all hypotheses that require information on population statistics of marine mammals.

BEMP PROJECT OVERVIEW NO. 1-16

TITLE:	Foraging behavior of gray whales in relation to patch dynamics of their benthic prey along Vancouver Island, British Columbia
PRINCIPAL INVESTIGATOR:	J.A. Guerrero
AFFILIATION:	Moss Landing Marine Laboratories, Moss Landing, CA
SOURCE:	Sixth Biennial Conference on the Biology of Marine Mammals. Abstracts. Nov. 22-26, 1985. Vancouver, B.C.
RELEVANT BEMP HYPOTHESIS NUMBER(S):	1

BRIEF PROJECT DESCRIPTION

Gray whale foraging behaviour over highly patchy swarms of epifaunal mysid prey was strikingly different then that over relatively continuous beds of infaunal amphipod prey. Divers identified mysid crustaceans swarming in discontinuous bands over rocky substrate in association with feeding gray whales. Within these areas, highly localized mysid patches differed from each other in biomass and abundance by as much as 500%. Whales feeding in mysid areas generally made short dives (x = 1.9 min) which were highly variable in duration (s.d. = 1.4). Surface intervals were similarly short (x = 0.4 min) and highly variable in duration (s.d. = 0.4) and in number of blows per interval (x = 2.8, s.d. = 1.9). Mysid-feeding whales often inhaled only once between dives; these 1-blow surface intervals comprised up to 30% of all surfacings over particularly dense mysid patches. Unlike mysids, infaunal amphipods did not form highly dense localized patches. Whales feeding over amphipods rarely made short dives or short, one-blow surfacings. Instead, dives and surface intervals were consistently long and varied little in duration (dive x = 3.8 min, s.d. = 1.0; surface x = 0.8 min, s.d. = 0.1). The number of blows per surface interval were consistently high (x = 4.2, s.d. = 1.6). During continuous observations (1-30 hours) of individuals feeding was the most common behaviour noted. However, travelling and resting behaviours were also quantified, and were distinct from feeding and each other. Observations of extensive whale feeding activity over mysids, high biomass in mysid areas, and large total area of available mysid habitat suggest that mysids are the major prey of gray whales along the Vancouver Island coast.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

Bowhead whales are believed to concentrate their feeding activities in areas of higher than average prey density. This study provides comparative feeding data on a species related to the bowhead. Two research programs on bowhead feeding began in 1985 (Project Overviews 1-3 and 1-4).

BEMP PROJECT OVERVIEW NO. 1-17

TITLE:	Food and feeding of right whales in Cape Cod Bay, Massachusetts
PRINCIPAL INVESTIGATORS:	C.A. Mayo, C.A. Carlson and M.A. Gilmore
AFFILIATION:	Cetacean Research Program, Center for Coastal Studies, Provincetown, MA.
SOURCE:	Sixth Biennial Conference on the Biology of Marine Mammals. Abstracts. Nov. 22-26, 1985. Vancouver, B.C.
RELEVANT BEMP HYPOTHESIS NUMBER(S):	1

BRIEF PROJECT DESCRIPTION

In Cape Cod waters right whales (Eubalaena glacialis) 'skim' feed at the surface of the sea permitting direct investigations of prey density, feeding strategies, and consumption rates. The distribution and behavior of right whales in skim feeding aggregations and the characteristics of associated surface zooplankton patches were studied during the winter and early spring of 1984 and 1985. In order to describe spatial strategies, the swimming patterns of whales in feeding areas were observed and videotaped. Zooplankton patches were characterized from collections made with metered nets of 431 µm mesh towed at the surface. The dominant zooplankters were calanoid copepods (Calanus finmarchicus and Pseudocalanus minutus) and cirripede larvae. The average value for total copepod concentration in areas where whales were present and feeding was 4340/cu m (n = 20), at stations where whales were present but not feeding was 2014/cu m (n = 12), and at stations where no whales were present was 400/cu m (n = 10). A comparison of plankton concentrations at right whale feeding and non-feeding areas suggests a feeding threshold of approximately 1100 copepods/cu m. The small-scale swimming patterns of right whales were compared with zooplankton density data in right whale feeding areas and contrasted with foraging strategies of other mammals which depend on similarly patchy resources. Based on filteration studies of right whale baleen, estimates of gape area, calculations of feeding velocity, and observed plankton densities in the feeding areas, estimates of wet weight intake of filterable plankton at maximum feeding velocity were: (1) 61 kg/hr in areas of the greatest plankton concentration observed during the study; (2) 21 kg/hr at mean zooplankton concentration in feeding areas; and (3) 2 kg/hr at mean zooplankton density at stations where whales were not present. Consumption estimates, expressed as caloric intake, were compared and contrasted with existing models of mysticete energetics. The authors concluded that the movement, aggregation and behavior of right whales observed in the winter and spring in their study area reflected foraging strategies related to patchy zooplankton distribution.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

Bowhead whales are believed to concentrate their feeding activities in areas of higher than average prey density. This study provides comparative feeding data on a species related to the bowhead. Two research programs on bowhead feeding began in 1985 (Project Overviews 1-3 and 1-4).

HYPOTHESIS NO. 2.

VARIOUS FACILITIES AND ACTIVITIES ASSOCIATED WITH OFFSHORE HYDROCARBON DEVELOPMENT WILL AFFECT THE WHITE WHALE HARVEST

INTRODUCTION

Participants at the 1985 BEMP workshop confirmed the validity of this hypothesis. However, Links 3 and 4 were re-worded and de-emphasized in 1985 since review of existing information indicated that factors other than timing of break-up may have considerable influence on the timing of entry of white whales into Niakunak and Kugmallit bays.

NEW INFORMATION

As in 1984, the petroleum industry collected information on ice conditions, including time of break-up, via SAR imagery (Project Overview 2-1). This information, as well as the report on the effects of icebreaking on the ice regime of Admiralty Inlet (Project Overview 2-2), provide information relevant to the assessment of Links 1 and 2 of the hypothesis.

Project Overviews 2-3 to 2-7 all provide information relevant to the assessment of Links 5 and 6 as does Overview 1-15. The visual and photographic surveys described in Overview 2-3 provide distributional data as well as providing correction factors for future surveys. Other developments in remote sensing of marine mammals (see Overviews 1-15 and 2-10) may also provide better methods for assessing numbers and distribution of white whales.

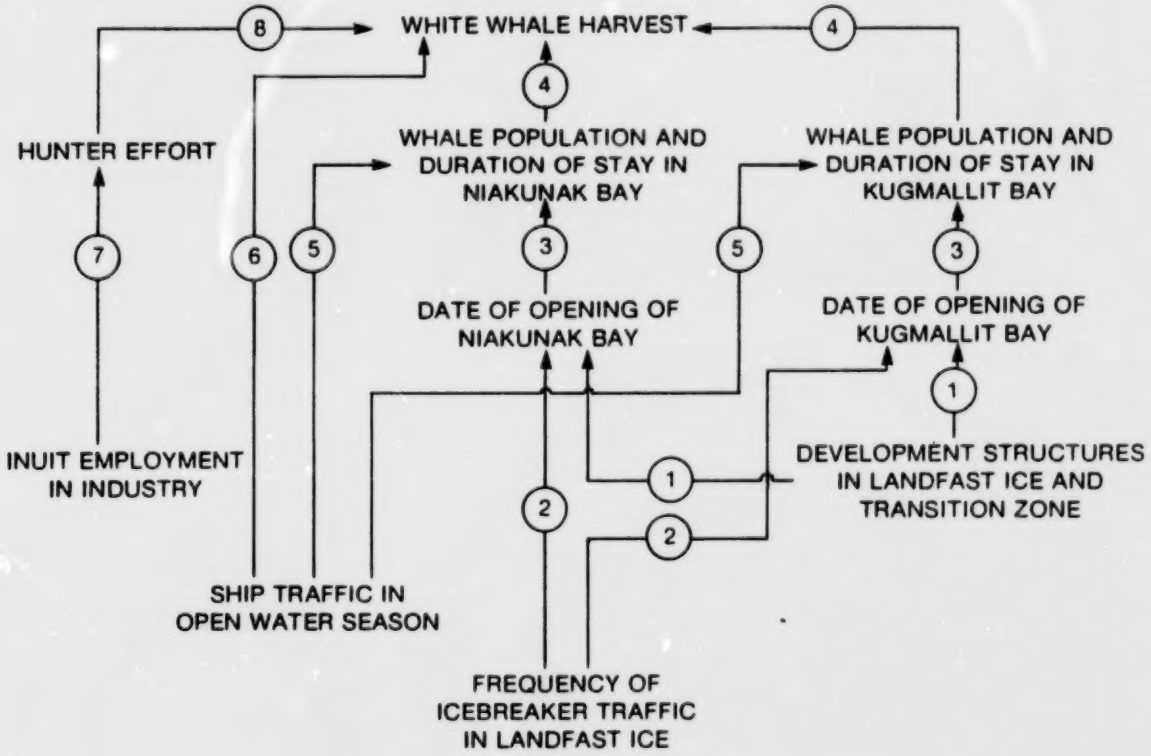
The study described in Overview 2-4 was an attempt to assess directly the effects of boat traffic on white whale behaviour and movements through the use of recorded vocalizations. Although few data were obtained in 1985 because of equipment problems, the technique has the potential to provide detailed information about white whale responses to boats. Background information relevant to this study is provided by the study of white whale vocalizations described in Overview 2-5. Comparative information about reactions of white whales to ships in the eastern Arctic is provided by studies at the Lancaster Sound ice edge (Overviews 2-6 and 2-7).

Neither of the studies described in Overviews 2-8 and 2-9 provides information directly related to any of the links in Hypothesis 2. However, both provide background information on white whales that could be relevant to assessments of the status of the population and, therefore, response of the population to changes in harvest levels.

FIGURE 2-1

THE EFFECTS OF VARIOUS FACILITIES AND ACTIVITIES ASSOCIATED WITH OFFSHORE HYDROCARBON DEVELOPMENT ON THE WHITE WHALE HARVEST

A. Offshore structures will reduce the white whale harvest.
B. Frequent icebreaker traffic in landfast ice will increase the white whale harvest.
C. Open water ship traffic in the Mackenzie Estuary will alter white whale distribution and lead to changes in harvest levels.



LINKAGES

1. Artificial islands off the Mackenzie Delta will delay the regional break-up of landfast ice.

2. Icebreaker traffic in the landfast ice in spring will advance the break-up of ice barriers across Kugmallit and Niakunak bays.

3. The timing of break-up of the landfast ice influences the timing of entry, and the numbers and the duration of residence of white whales in Niakunak and Kugmallit bays.

4. The numbers and the duration of residence of white whales in Kugmallit and Niakunak bays will influence the white whale harvest.

5. Ship passages through Niakunak and Kugmallit bays will disturb white whales, and this will reduce the number of animals that frequent the bays and/or the time that whales spend in the bays.

6. Ship traffic in Niakunak and Kugmallit bays will lead to changes in the distribution of whales in the bays, and these changes will lead to changes (probably reductions) in the harvest levels. In addition, ship traffic could directly interfere with hunting activities by frightening whales that are being hunted.

7. Increased Inuit employment by the oil industry and various supporting businesses will lead to changes in hunter effort.

8. Changes in hunter effort and experience will lead to changes in white whale harvest.

BEMP PROJECT OVERVIEW NO. 2-1

TITLE:	1985 SAR ice imagery of the Beaufort Sea
PRINCIPAL INVESTIGATORS:	Petroleum industry personnel
AFFILIATION:	Not applicable
FUNDING SOURCE:	Not applicable
EXPECTED COMPLETION DATE:	Complete
RELEVANT BEMP HYPOTHESIS NUMBER(S):	2

BRIEF PROJECT DESCRIPTION

As part of normal operational monitoring procedures by the petroleum industry, synthetic aperture radar (SAR) overflights were conducted over the Canadian Beaufort Sea on an essentially daily basis from June 16 to November 13, 1985. In addition, about 40 flights were made over the Alaskan Beaufort Sea from July 3 to October 25, 1985. Features such as ice boundaries, cracks, leads, ridges and ships' tracks are easily identifiable on SAR imagery. Although the data collected during this monitoring are proprietary to the well partners, they are available for reference in the Dome offices for the purposes of BEMP-related research.

RELATIONSHIP AND RELEVANCE TO BEAUFORT ENVIRONMENTAL MONITORING PROJECT

Linkages 2 to 4 of Hypothesis 2 indicate that icebreaker traffic associated with offshore hydrocarbon development may advance the timing of the break-up of the landfast ice sheet across Kugmallit and Niakunak bays, and thereby affect the white whale harvest. Alternatively, Link 1 of this hypothesis suggests that the presence of artificial islands off the Mackenzie Delta will delay the regional break-up of the landfast ice. The daily SAR imagery of sea ice in the vicinity of several active and abandoned artificial islands in the offshore Beaufort provides an excellent database for the investigation of break-up patterns. The validity of Links 1 and 2 can be easily evaluated through the use of the SAR ice imagery database.

BEMP PROJECT OVERVIEW NO. 2-2

TITLE:	The MV Arctic ship track and its effect on hunter travel and ice break-up in Admiralty Inlet, northern Baffin Island
PRINCIPAL INVESTIGATORS:	A.G. Strandberg, U. Embacker, L.Sagriff
AFFILIATION:	FMS Engineers Inc./Canarctic Shipping
FUNDING SOURCE:	NOGAP (INAC)
EXPECTED COMPLETION DATE:	Complete
RELEVANT BEMP HYPOTHESIS NUMBER(S):	2, 4 and 6

BRIEF PROJECT DESCRIPTION

This study was initiated in response to concerns of Inuit hunters from Arctic Bay that the icebreaking associated with passage of the MV Arctic through Admiralty Inlet to Nanisivik Mines would affect their traditional on-ice narwhal hunt. This study specifically addressed the effects of spring (June-July) icebreaking activities on ice break-up and hunter travel.

The final report provided a detailed discussion of the monitoring of break-up during June-July of 1984, including on-ice field investigations and observations recorded during helicopter overflights. Photographic records of ice conditions to show changes in ship track width and composition, as well as macro-shifts in ice floe geometry, were presented.

A ten-year retrospective review of the break-up process in Admiralty Inlet, using all available remote sensing and satellite imagery data, was conducted. Comparison of conditions prior to 1978, the first year MV Arctic penetrated the ice of the inlet, with subsequent years indicated that icebreaking may have advanced break-up slightly in some years. However, the date of break-up is very variable in the absence of icebreaking and no firm conclusion could be made about the degree of advancement.

Tests of the ability of hunters, with their snowmobiles and komatiks, to cross the ship track were conducted after the inbound passage (29 June-4 July) and again after the outbound passage (8 July). After the inbound passage, there was no difficulty in finding solid crossing locations and it was difficult to locate a site in the track where a snowmobile or komatik would break through. However, after the outbound passage, crossings were difficult to locate and of marginal safety. This was attributed to re-milling of the ice by the second passage of the ship and lack of re-freezing due to above-zero air temperatures.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

Several of the hypotheses discussed in the 1983-84 BEMP Final Report concern the potential effects of ship traffic on the stability of the ice and subsequent impacts on marine mammal populations. One linkage in Hypothesis 2 suggests that icebreaker traffic in the landfast ice in spring will advance the break-up of ice barriers, while another linkage in Hypothesis 6 states that "icebreaker traffic in Amundsen Gulf will move the stable ice edge to

the east in winter and spring". The present study provides virtually the only direct evidence relating to these hypotheses. Thus, even though the study was conducted in the eastern Arctic, it provides important information relating to the prediction of the impacts of winter shipping in the Beaufort Sea.

BEMP PROJECT OVERVIEW NO. 2-3

TITLE:	White whale surveys in the Beaufort Sea.
PRINCIPAL INVESTIGATORS:	T. Strong, P. Norton
AFFILIATION:	Fisheries and Oceans Canada, Freshwater Institute; PN Enterprises
FUNDING SOURCE:	ESRF, NOGAP, DIAND
EXPECTED COMPLETION DATE:	1986
RELEVANT BEMP HYPOTHESIS NUMBER(S):	2

BRIEF PROJECT DESCRIPTION

This overview covers three related projects:

1. Visual surveys of white whales undertaken by PN Enterprises;

2. Photographic surveys of white whales by DFO; and

3. Surveys of selected transects by both methods.

The objective of the integrated program was to compare simultaneous counts of the number of whales in an area using a visual aerial survey technique and a photographic aerial survey technique. Comparison of the results will indicate a relative correction factor for each technique of the number of whales present but not detected and a rough calibration factor to apply when comparing the results obtained by one method to those obtained by the other. Data from the visual surveys have been analysed but those from the photographic surveys are not yet available.

Systematic aerial surveys for whales have been conducted annually in the Mackenzie Estuary and in the offshore Beaufort since 1972 and 1980, respectively. All surveys employed the same visual survey technique. In some years, attempts were made to examine the number of surfaced whales missed by observers, by comparing counts of two observers on the same side of the aircraft, but no comparison of the results obtained by two different survey methods has been attempted. In the eastern Arctic such a comparison has been done and the results indicate that visual observers miss some whales that can be detected in photographs.

There are advantages and disadvantages to each technique. The visual survey technique affords a real-time observation period (whale movement can be used as a sighting cue; a survey can be modified or interrupted when appropriate to maximize data collection). The visual technique is also cost-effective and less limited by weather than the photographic survey technique. However, the photographic technique provides a permanent record of the observations which allows for easy comparison of observer effectiveness and assessment of whale parameters, such as whale length and distances between whales, which cannot be accurately measured using the visual technique.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

The results of this project will be relevant to the collection of distributional data required for assessment of Hypothesis 2(c).

BEMP PROJECT OVERVIEW NO. 2-4

TITLE:	Assessment of white whale responses to boat traffic through detection of vocalizations
PRINCIPAL INVESTIGATOR:	T. Strong
AFFILIATION:	Fisheries and Oceans Canada, Freshwater Institute
FUNDING SOURCE:	NOGAP
EXPECTED COMPLETION DATE:	1987
RELEVANT BEMP HYPOTHESIS NUMBER(S):	2

BRIEF PROJECT DESCRIPTION

This study began in 1985 with initial field trials of sonobuoy deployment in the inner Mackenzie estuary. The study has three objectives:

1. to assess sound transmission in the very shallow water of the inner estuary;

2. to determine whether changes in vocalization rate or type occur in the presence of disturbance from either industry or hunting boats; and

3. to determine, by triangulation, movements of whales in response to boat traffic.

Equipment problems in 1985 resulted in few data being collected but the study will continue in 1986.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This research will provide information that is directly relevant to Hypothesis 2(c). Results of this study will show whether distribution of white whales does, indeed, change in response to ship traffic.

BEMP PROJECT OVERVIEW NO. 2-5

TITLE:	The vocal behaviour of white whales, Delphinapterus leucas, summering in an arctic habitat
PRINCIPAL INVESTIGATOR:	B.L. Sjare
AFFILIATION:	McGill University
SOURCE:	Sixth Biennial Conference on the Biology of Marine Mammals. Abstracts. Nov. 22-26, 1985, Vancouver, B.C.
RELEVANT BEMP HYPOTHESIS NUMBER(S):	2

BRIEF PROJECT DESCRIPTION

The underwater vocalizations of white whales, Delphinapterus leucas, summering at Cunningham Inlet, N.W.T., (74°05'N, 93°45'W), were recorded from mid-July to mid-August 1983. Vocalizations were classified into one of eight major whistle contour types or one of five pulsed call categories which included click series, three types of pulsed tones and noisy vocalizations. To determine the relationship between vocalizations and observed behavioural activities, a total of 63 2-min samples recorded when whales were quiescent, swimming in a directive manner, socially interactive, and alarmed were analysed. Differences in the total number of whistles, pulsed tones (including noisy vocalizations) and click series emitted/whale/minute during each behavioural activity were examined. The number of whistles emitted did not differ with changes in behavioural activity (χ^2 = 31.85, df = 3, p = 0.0001) and the total number of pulsed tones emitted (χ^2 = 7.33, df = 3, p = 0.062) did show distinct trends. More specific analyses considering each of the major whistle contour types, the three types of pulsed tones and noisy vocalizations were also completed. The rate at which four of the whistles, two types of pulsed tones and the noisy vocalizations were emitted was influenced by behavioural activity. These results reveal a general association between white whales' behavioural activity and the types of vocalizations emitted.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This study is of interest to BEMP in as much as it provides input into the assessment of the utility of underwater vocalizations as a census technique (see Project Overview No. 2-4). It may also be relevant to the detection of responses by white whales to industrial activity. BEMP Project Overview No. 2-6 indicates that white whales respond to ships with distinctive alarm calls.

BEMP PROJECT OVERVIEW NO. 2-6

TITLE:	Reactions of white whales and narwhals to ship traffic and icebreaking along ice edges in the eastern Canadian High Arctic: 1982-1984
PRINCIPAL INVESTIGATORS:	K.J. Finley, R.A. Davis
AFFILIATION:	LGL Ltd. King City, Ontario
FUNDING SOURCE:	Industry and government (managed by INAC)
EXPECTED COMPLETION DATE:	Complete
RELEVANT BEMP HYPOTHESIS NUMBER(S):	2

BRIEF PROJECT DESCRIPTION

The purpose of this study was to determine the reactions of narwhals and white whales to icebreaking activities in Lancaster Sound and Admiralty Inlet. Three years of data were collected in the early summer period during the first passage of the ore carrier MV ARCTIC (with attendant icebreaker support) to Nanisivik Mines. The study involved documentation of the behaviour of whales along the ice edge (1) before the arrival of the ship(s), (2) during the period of ship arrival and icebreaking in the area and (3) following the passage of the vessels and associated disturbance. Data collection techniques included acoustic monitoring of ambient noise (including whale vocalizations) and ship noise as well as on-ice and aerial observations of whale behaviour and movements.

Ambient noise was found to be dominated by animal sounds, including the vocalizations of narwhals, white whales and bearded seals, and noise from ice movements. There were temporal variations in the intensity of ambient noise, with intensities generally lower at night and during calm periods. Intensities were also lower at a station 11 km from the ice edge than at the ice edge.

Noise recorded from the MV ARCTIC and accompanying icebreakers was typical of the noise levels produced by large ships and the reactions of the whales were, thus, not likely the result of unusual characteristics of these particular ships. Tones from the ships were first detected by the recording equipment when a ship was 105 km away in 1982 and 132 km away in 1983. White whales responded to the noise when the ship was as far away as 84 km. Ship noise was fairly steady when the ship was steaming through open water but was highly variable when the ship was ramming in heavy ice.

Approach of the ship caused rapid movement of white whales along ice edges. This often resulted in clumped distribution patterns with major concentrations occurring in coastal areas adjacent to ice edges and large gaps in distribution along the ice edge in the direct path of the ship. The ship also caused displacement of narwhals but not to the same extent as white whales.

The behaviour patterns of white whales and narwhals in response to the approaching ship were quite different although both eventually moved away from the ship's path. White whales swam rapidly away from the source of the ship noise and occasionally reached speeds in excess of 20 km/h. During such

movements, they rose unusually high out of the water and undertook long shallow dives close to or beneath the ice edge. Pod integrity was lost (or became less obvious) during these movements and diving appeared asynchronous. These rapid movements were highly coordinated in one direction over long segments of the ice edge; dense herds sometimes formed at the terminus of these movements. These surface behaviours were associated with emission of distinctive 'alarm' calls.

Narwhals, on the other hand, initially responded to approaching ships by moving slowly or lying motionless close to the ice edge. Rather than diving, they tended to sink during submergence. Often narwhals huddled tightly in pods, sometimes in physical contact. The movements of pods or individuals appeared to be independent and grouping of pods into herds did not occur. During this initial response narwhals ceased to produce their normal underwater sounds. As the ship approached closer narwhals tended to disperse along the ice edge or offshore.

The authors discuss the lack of any apparent habitauation over the three years of study and note that white whales in other areas have demonstrated some degree of habituation to shipping. The authors suggest that the lack of habituation may be related to the fact that white whales are merely waiting at the ice edge for break-up and have no 'vested interest', such as they might in a feeding area, in remaining in a particular area when a ship approaches.

RELATIONSHIP AND RELEVANCE TO BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This study was the first program of this type conducted in the eastern Arctic and the most comprehensive study of the reaction of white whales to ship traffic initiated to date. The study provides information on sound transmission, vocalizations and the behavioural responses of whales to infrequent ship passages. Although the study was conducted in the eastern Arctic, the results are of value in interpreting the observed reactions of white whales to ships in the nearshore Beaufort Sea (Hypothesis 2).

BEMP PROJECT OVERVIEW NO. 2-7

TITLE:	Reactions of white whales and narwhals to ship traffic and ice-breakers at the Admiralty Inlet ice edge
PRINCIPAL INVESTIGATOR:	S. Cosens
AFFILIATION:	Fisheries and Oceans Canada, Freshwater Institute
FUNDING SOURCE:	NOGAP
EXPECTED COMPLETION DATE:	1988
RELEVANT BEMP HYPOTHESIS NUMBER(S):	2

BRIEF PROJECT DESCRIPTION

This research project is presently in the planning stages and is an outgrowth of the studies conducted at the Admiralty Inlet ice edge in 1982-1984 (BEMP Project Overview No. 2-6). The study is designed to quantify vocal and behavioural responses to ship traffic and icebreaking. Whales that are displaced will be followed and further observations of vocalizations and behaviour made to determine whether displaced animals remain agitated for extended periods.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

The study previously conducted at the Admiralty Inlet ice edge (BEMP Project Overview 2-6) provided information about sound transmission, vocalizations and behaviour of white whales in response to infrequent ship traffic. This continuation of that study will provide more detailed information about responses by whales to ships. Although the study is being conducted in the eastern Arctic, the results will be of value in interpreting the observed reactions of white whales to ships in the nearshore Beaufort Sea (Hypothesis 2).

BEMP PROJECT OVERVIEW NO. 2-8

TITLE:	Beaufort Sea white whale study
PRINCIPAL INVESTIGATOR:	T. Strong
AFFILIATION:	Fisheries and Oceans Canada, Freshwater Institute
FUNDING SOURCE:	DFO, NOGAP
EXPECTED COMPLETION DATE:	1987
RELEVANT BEMP HYPOTHESIS NUMBER(S):	2

BRIEF PROJECT DESCRIPTION

This project was initiated in 1981 to obtain information on the population status, distribution and stock identity of white whales hunted in the Mackenzie Estuary, and to collect catch/effort data for the Mackenzie domestic harvest. The overall purpose of the program is to develop management recommendations concerning the Mackenzie white whale population.

Six local persons were contracted in 1985 to obtain information through hunter interviews on catch/effort, total lengths and the sex of harvested whales. In addition, the contractors collected biological material from harvested whales, including necessary material to determine age and reproductive status. Stomach contents were not collected from harvested animals, although stomachs were examined *in situ* and did not contain much prey.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

'Component A' of the monitoring program recommended in the 1983-84 BEMP Final Report included continuation of the annual monitoring of white whale harvest levels in the Mackenzie Estuary. This program is consistent with such recommendations, although it was initiated and is being continued for reasons other than the BEMP process. Information collected during the course of this annual monitoring program is not directly relevant to any of the linkages in Hypothesis No. 2, but does provide important data on various population parameters of the Mackenzie white whale stock (e.g., age, length).

BEMP PROJECT OVERVIEW NO. 2-9

TITLE:	Reproductive parameters of beluga whales in northwest Alaska
PRINCIPAL INVESTIGATOR:	J.J. Burns
AFFILIATION:	Alaska Department of Fish and Game
SOURCE:	Sixth Biennial Conference on the Biology of Marine Mammals. Abstracts. Nov. 22-26, 1985, Vancouver, B.C.
RELEVANT BEMP HYPOTHESIS NUMBER(S):	2

BRIEF PROJECT DESCRIPTION

Preliminary results of white whale investigations in northwest Alaska have already been reported. Additional information obtained in 1980 to 1983, combined with previous data, indicate the following reproductive parameters: a sex ratio of 1:1, first pregnancy at age four to seven, first birth at age five to eight, reproductive activity throughout life in females, a pregnancy rate (early pregnancy) of 0.335, a rate of calf production estimated at 0.104, and a population structure that includes 32-33% sexually mature females. The birth period is prolonged, extending from April to perhaps August with a peak in mid-June to late July. Peak period of breeding is not presently known.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

Although it is not entirely clear that northwestern Alaskan white whales are part of the same reproductive group as white whales of the eastern Beaufort Sea, these groups do winter in the same area and are subject to at least some of the same environmental influences. Thus, this study provides reproductive parameters that are probably elevant to white whales harvested from the Mackenzie estuary.

BEMP PROJECT OVERVIEW NO. 2-10

TITLE:	Marine mammal underwater detection/ census techniques
PRINCIPAL INVESTIGATORS:	M.C.S. Kingsley, P. Richard
AFFILIATION:	Fisheries and Oceans Canada, Freshwater Institute
FUNDING SOURCE:	OERD and DFO
EXPECTED COMPLETION DATE:	March 1988
RELEVANT BEMP HYPOTHESIS NUMBER(S):	1 and 2

BRIEF PROJECT DESCRIPTION

This research and development program has two related objectives:

1. development of passive underwater sound detection and localization techniques to improve land- or ice-based visual counts of marine mammals; and

2. development of active underwater detection techniques (sonar) to improve land- or ice-based visual and aerial visual or photographic surveys.

A review study addressing these two objectives was completed in early 1984 to establish the state-of-the-art with respect to passive and active underwater sound techniques and their potential application to the censusing of marine mammals. The study examined technical and logistical limitations of equipment, characteristics of marine mammal vocalizations, and included an evaluation and cost review of various equipment. In 1984, a baseline study of narwhal and white whale vocalizations was initiated in the eastern Arctic and this study was continued in 1985. Results to date are primarily from narwhals and indicate that:

1. qualitative distinctions between large and small groups are possible but, since large groups of narwhals often produce a continuous series of clicks, precise enumeration is probably not possible;

2. narwhals may be completely silent while travelling purposefully; and

3. males produce a much wider range of vocalizations than females.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

The results of this research and development project may ultimately have application to various research and monitoring programs directed at marine mammals in the Beaufort region. Passive acoustic techniques were discussed in the 1983-84 BEMP final report in relation to Hypothesis No. 1 report, but no conclusions or recommendations were made.

HYPOTHESIS NO. 3

MARINE VESSEL ACTIVITIES, SEISMIC OPERATIONS, DREDGING OPERATIONS, AIRCRAFT OVERFLIGHTS AND ACTIVE OFFSHORE PLATFORMS/ARTIFICIAL ISLANDS WILL REDUCE THE SIZE OF POPULATIONS OF RINGED AND BEARDED SEALS IN THE BEAUFORT SEA

INTRODUCTION

This hypothesis focuses on the cumulative effects of vessels, seismic activities, dredging, aircraft and platform activities on the energy balance of ringed and bearded seals through (1) reductions in the amount of time available for feeding and/or (2) increased energy costs due to avoidance behaviour. A negative energy balance could lead to reduced reproductive rates in ringed and bearded seal populations. Participants in the 1985 BEMP workshop confirmed the validity of this hypothesis but noted that the cumulative effect of all links would be difficult to detect with present techniques and inconsequential on a population wide basis.

NEW INFORMATION

Two studies that were discussed at the 1985 BEMP workshop are now complete or almost so (Project Overviews 3-1 and 3-2). The first of these studies, conducted by the Freshwater Institute (DFO), was designed to assess whether the distribution and abundance of hauled-out ringed seals were affected by oil and gas activities in the Beaufort Sea. No correlation between low densities of hauled-out seals and proximity to industrial activities was found over the four years of study.

The study by T. Smith (Arctic Biological Station) assessing population characteristics of ringed seals in the Beaufort Sea over a 12-yr period (Project Overview No. 3-2) is expected to be published in 1986. The data in this report provide strong evidence for the validity of Link 9.

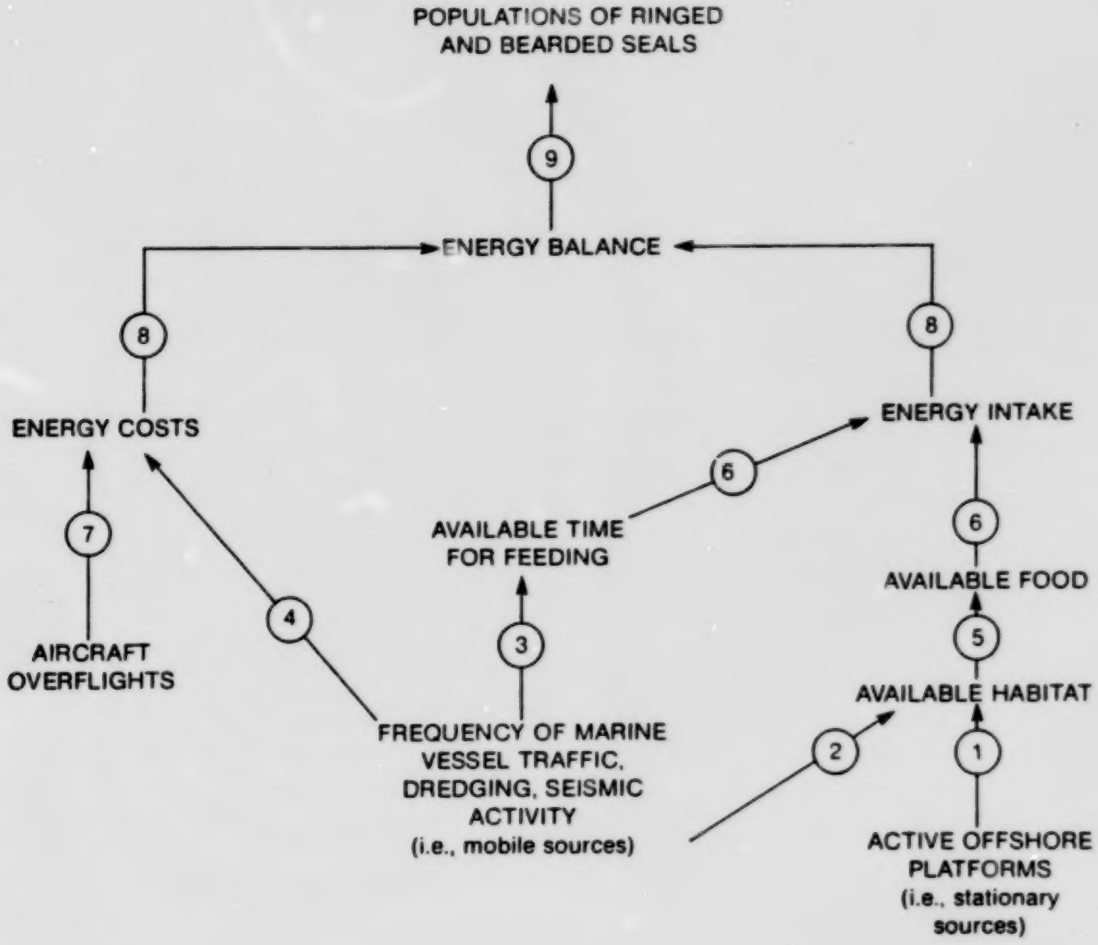
Two studies conducted in the Chukchi and Alaskan Beaufort seas (Project Overview No's 3-3 and 3-4) are relevant to this hypothesis. One study has attempted to assess effects of on-ice seismic activities on ringed seal distribution and use of snow-structures. This study has not yet produced conclusive results and is continuing. A related study has assessed ringed seal use of snow structures by telemetry. This study also has the potential to provide correction factors for studies assessing seal populations based on counts of hauled-out seals.

Two other methodological studies (Project Overviews 3-5 and 3-6) were conducted in 1985. One study provides a method for estimating the number of seal holes per unit area. The other contributes to the development of correction factors for visual estimates of seal numbers through the use of aerial photography.

FIGURE 3-1

THE EFFECTS OF VARIOUS OFFSHORE ACTIVITIES AND FACILITIES ON POPULATIONS OF RINGED AND BEARDED SEALS IN THE BEAUFORT SEA

Marine vessel traffic, seismic activities, dredging operations aircraft overflights and active offshore platforms/islands will reduce the size of populations of ringed and bearded seals in the Beaufort sea



LINKAGES

1. Each active offshore platform will result in the exclusion of ringed and bearded seals from some habitat.

2. Marine traffic (ships, dredges, seismic vessels) will exclude ringed and bearded seals from available habitat.

3. Each passage of a ship or other marine vessel will reduce the feeding time available to ringed and bearded seals.

4. Each passage of a vessel will increase the energy expenditure of seals because of avoidance behaviour.

5. The available aquatic habitat can influence the level of available food.

6. The amount and quality of available food and the time available for feeding determine energy intake.

7. Noise from aircraft will disturb hauled-out seals and lead to increased energy costs.

8. Energy intake and costs determine energy balance.

9. The energy balance of a seal determines its survival and its ability to reproduce. The energy balance of the individuals in a population influences the reproductive capacity and health of the population.

BEMP PROJECT OVERVIEW NO. 3-1

TITLE:	Beaufort Sea ringed seal monitoring study
PRINCIPAL INVESTIGATOR:	M.C.S. Kingsley
AFFILIATION:	Fisheries and Oceans Canada, Freshwater Institute
FUNDING SOURCE:	ESRF, DFO
EXPECTED COMPLETION DATE:	Complete
RELEVANT BEMP HYPOTHESIS NUMBER(S):	3

BRIEF PROJECT DESCRIPTION

The purpose of this study was to monitor the abundance and distribution of ringed seals relative to oil and gas industry activities in the Beaufort Sea to determine if these activities were having detectable effects on seals.

During the 1974-1979 Beaufort Sea Project, aerial surveys were flown every June to count seals hauled out on the sea ice. Analysis of the data collected over the six years indicated large annual fluctuations in the density and estimated abundance of populations of visible seals. In 1981, when hydrocarbon exploration activity in the Beaufort Sea was intensified, a second series of ringed seal surveys with a more restricted but denser coverage was initiated off the Tuktoyaktuk Peninsula. The survey design incorporated north-south transects spaced every 15' of longitude from 129°15'W to 136°30'W off the Mackenzie Delta and Tuktoyaktuk Peninsula. These transects were approximately 160 km long and were rounded to the nearest 20' of latitude at their offshore ends.

A control area in Amundsen Gulf and Prince Albert Sound was included in the study design to allow comparison of any population changes in the Beaufort Sea with variation in an area which is both prime pupping habitat and unaffected by hydrocarbon exploration activities. The transects were spaced every 20' of longitude from 114°40'W to 123°00'W and extended south to 70°30'N in Amundsen Gulf.

No association between low densities of seals and proximity to industrial activity was found during the four years of this program. In fact, it appeared that higher densities of seals occurred near active sites of industry activity in 1982 and 1983. This may be because exploration has been most concentrated in areas near the shear zone where high densities of seals tend to occur. This study will be published as ESRF report 012 during 1986.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

Hypothesis No. 3 states that 'Marine vessel traffic, seismic activities, dredging operations, aircraft overflights and active offshore platforms/ islands will reduce the size of the Beaufort Sea populations of ringed and bearded seals'. However, the hypothesis was considered unlikely given the anticipated hydrocarbon development scenario for the region, and as a

result, no research or monitoring was recommended. However, the present seal monitoring study was initiated in 1981 prior to BEMP, and is directly relevant to Link 1 which states that 'Each active offshore platform will result in the exclusion of ringed and bearded seals from some habitat'. The results of past seal surveys support the BEMP conclusion that the extent of exclusion would be inconsequential and in most instances limited to the physical extent of the island/structure, and that the cumulative effects of all links in this hypothesis would probably be inconsequential.

BEMP PROJECT OVERVIEW NO. 3-2

TITLE:	Changes in the population dynamics of ringed seals in the Amundsen Gulf
PRINCIPAL INVESTIGATOR:	T.G. Smith
AFFILIATION:	Fisheries and Oceans Canada, Arctic Biological Station
EXPECTED COMPLETION DATE:	1986
RELEVANT BEMP HYPOTHESIS NUMBER(S):	3, 4 and 6

BRIEF PROJECT DESCRIPTION

This study involves the compilation and integration of extensive amounts of data collected by the Arctic Biological Station on the Amundsen Gulf ringed seal population during the period from 1971 to 1983. This long-term program has included investigation of various aspects of ringed seal population structure, recruitment, annual movements and physiological condition. Samples were collected in several areas within Amundsen gulf including Minto Inlet, Prince Albert Sound, Prince of Wales Strait and Cape Parry.

Specific aspects of the program involve:

1. Cohort Analysis. Annual life tables and cohort analysis from a large collection of specimens will allow estimation of age-specific survivorship.

2. Reproductive Biology. Examination of reproductive systems will provide estimates of age-specific reproductive rates and also allow investigation of the mechanism for abortion and failure of some seals to mate. In addition, breeding habitat surveys will provide a direct index of reproduction for each year and serve as a check on information obtained from examination of reproductive systems.

3. Seasonal and Annual Movements. Collected specimens will be examined for evidence of geographical segregation of age classes or sexes.

4. Condition indices will be derived from measurements of body fat, blood parameters, and in some cases, stomach contents.

Many aspects and components of this research have been presented elsewhere. The overall integration and interpretation of information resulting from this study, including resolution of seasonal and year-to-year changes, has required the used of computerized techniques of data analysis and simulation. The author expects to provide the results of this research in a Canadian Bulletin of Fisheries and Aquatic Sciences in 1986.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This program is relevant to Hypotheses No. 3, 4 and 6. There is concern that icebreaker traffic through Amundsen Gulf will affect the ringed seal and polar bear populations. Some effects could result from alterations to ice type, coverage and location. Participants in the second workshop of the Beaufort Environmental Monitoring Project concluded that, although such ship-induced destabilization of the Amundsen Gulf ice cover was not highly probable, this area of concern deserved further consideration because of the potential seriousness of resultant impacts on seal and bear populations. Analysis of existing data was recommended to examine the effects of yearly changes in ice conditions on the distribution and abundance of marine mammal populations. The comprehensive time series of ringed seal data for Amundsen Gulf collected by the Arctic Biological Station was identified as an important source of information for such an analysis. Examination of the 12 years of data will allow analysis of the relationship between variations in ice cover (most notably the extreme ice years of 1971, 1978 and 1981) and changes in ringed seal population parameters.

BEMP PROJECT OVERVIEW NO. 3-3

TITLE:	Distribution, relative abundance, and potential displacement of ringed seals in Alaska.
PRINCIPAL INVESTIGATORS:	K.J. Frost, J.J. Burns and L.F. Lowry
AFFILIATION:	Alaska Dep. of Fish and Game
SOURCE:	Sixth Biennial Conference on the Biology of Marine Mammals. Abstracts. Nov. 22-26, 1985. Vancouver, B.C.
RELEVANT BEMP HYPOTHESIS NUMBER(S):	3, 4

BRIEF PROJECT DESCRIPTION

Distribution and abundance of ringed seals off Alaska have been examined through aerial strip transect surveys of hauled-out seals conducted in May-June of 1970-1985, and on-ice searches for seal lairs using trained dogs in April-May 1982-1984. Highest densities of seals (0.9-7.1/sq nmi) have been found on Chukchi Sea shorefast ice, intermediate densities (0.6-2.4/sq nmi) on Beaufort Sea shorefast ice, and lowest densities (0.1-0.4/ sq nmi) on pack ice. Highest densities of hauled-out seals occur in areas with 40% or less ice deformation. Most lairs were found in shorefast ice with 20-40% deformation. The highest densities of ringed seal structures were found in the northern Bering and Chukchi seas and the lowest densities in the Beaufort Sea. The relative abundance of structure types varied among study areas with highest proportions of pupping lairs in grids closest to shore in the Chukchi Sea (34-42%) and highest proportions of breathing holes in the Chukchi pack ice (60%) and the Beaufort (47%).

Shorefast ice also serves as a stable platform from which several phases of petroleum exploration can be undertaken. Studies have been conducted to examine the possible effects of such activities on ringed seals. Comparisons of seal densities, based on aerial surveys in 'seismic' and 'control' areas have produced ambiguous results. A previous study of the fate of seal structures showed that abandonment or altered use by ringed seals occurred mainly within 150 m of seismic lines. Interpretation of aerial and ground studies is complicated by factors such as the variability in seal haul-out patterns and in the natural incidence of alteration and refreezing of structures. Studies of the effects of industrial activities on ringed seals are continuing.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This study is of relevance to both Hypothesis 3 and to Hypothesis 4 which states that 'Increased frequency of icebreaker traffic through the landfast ice and through Amundsen Gulf will reduce ringed seal pup production and have subsequent effects on population levels'. The study provides information about use of disturbed areas by seals and data on densities of seals in different types of ice. The latter information is useful for assessing the numbers of seals that might be affected by icebreakers in both the Beaufort Sea and Amundsen Gulf.

BEMP PROJECT OVERVIEW NO. 3-4

TITLE:	Dependence by ringed seals on subnivean lairs
PRINCIPAL INVESTIGATOR:	B.P. Kelly
AFFILIATION:	University of Alaska
SOURCE:	Sixth Biennial Conference on the Biology of Marine Mammals. Abstracts. Nov. 22-26, 1985. Vancouver, B.C.
RELEVANT BEMP HYPOTHESIS NUMBER(S):	3, 4

BRIEF PROJECT DESCRIPTION

The objectives of this study were to determine:

1 the nature and degree of dependence by seals on breathing holes and lairs; and

2. the alternatives available to seals that have abandoned breathing holes and lairs.

The objectives were addressed during a three-year study using telemetric methods. Temporal and spatial haul-out patterns of 13 radio-tagged seals were recorded from early March to early June in the Beaufort Sea and in Kotzebue Sound. Each seal maintained two to four lairs; some lairs were used by more than one seal. The greatest distance between seal holes used by an individual was 4.5 km. Until late May, air temperatures (recorded via transmitting thermistors) inside lairs were consistently higher than outside air temperatures. Air temperature inside a typical lair averaged 27.0°C warmer than outside windchills in March, 26.2°C warmer in April and 16.4°C warmer in May. Lairs were heated by sea water (-2° to -3°C) and body heat from seals. Haul-out by seals caused abrupt temperature increases, as much as +10.2°C, inside lairs. Periods of haul-out were highly variable in length and frequency until late March for pupping females and, generally, May for all other seals, In late March and early April, two females, apparently caring for newborn pups, hauled out at least once per day and for significantly longer periods than they did before or after nursing. Diel haul-out patterns tended to become pronounced with mid-day peaks in May.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This study provides information on both (1) the dependence of ringed seals on subnivean lairs and (2) the alternatives that are available to seals that have abandoned lairs. The study also has the potential to provide correction factors to account for seals in the water during aerial counts of hauled-out seals in late spring. Such correction factors would be relevant to any research or monitoring program requiring knowledge of seal populations.

BEMP PROJECT OVERVIEW NO. 3-5

TITLE:	An application of removal sampling to estimate the density of ringed seal snow structures in Barrow Strait
PRINCIPAL INVESTIGATORS:	M.O. Hammill, T.G. Smith, M.C.S. Kingsley
AFFILIATION:	MacDonald College; Fisheries and Oceans Canada, Arctic Biological Station; Fisheries and Oceans Canada, Freshwater Institute
SOURCE:	Sixth Biennial Conference on the Biology of Marine Mammals. Abstracts. Nov. 22-26, 1985, Vancouver, B.C.
RELEVANT BEMP HYPOTHESIS NUMBER(S):	3, 4

BRIEF PROJECT DESCRIPTION

In a study designed to quantify the effects of certain habitat features on the density and distribution of ringed seals in the fast ice, it was necessary to develop a method which provided a reliable estimate of seal abundance. The suitability of the removal method to estimate the number of seal snow structures in a surveyed area was tested.

Labrador retrievers, trained to locate ringed seal structures, searched 12 different 4 sq km plots between March and June, in 1984 and in 1985. In each plot, all seal structures located by the dogs were marked. By treating the marked structures as removals (Zippin, Biometrics 12:163-189, 1956) the population of structures in each plot was estimated.

Nine of the areas searched in 1984 were also searched in 1985. Population estimates were obtained in six of the nine plots in 1984 and eight of the nine plots in 1985. Estimates from the remaining plots were not obtained because the probability of detection of seal structures failed to remain constant.

Comparisons of seal hole densities from all areas searched during the two years showed a slight decrease in density from a mean of 5.4 holes/sq km (s.d. = 2.7, n = 7) in 1984 to 4.5 holes/sq km (s.d. = 2.3, n = 10) in 1985. Large changes in distribution were noted between the two years. In 1985, the number of structures in three plots decreased by 44%, increased by 45% in one plot and remained unchanged in one plot. The reasons for this shift are not known.

The removal method proved to be satisfactory in estimating the number of seal holes per unit area. Application of the model permits the quantification of year-to-year changes in density and distribution of ringed seals within their breeding habitat.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This methodological study is not directly relevant to the assessment of validity of any of the links in Hypotheses 3 and 4. However, methods useful in evaluating densities and distributions of seals could be applicable to both hypotheses.

BEMP PROJECT OVERVIEW NO. 3-6

TITLE:	Comparative aerial survey of ringed seals in Amundsen Gulf
PRINCIPAL INVESTIGATOR:	M.C.S. Kingsley
AFFILIATION:	Fisheries and Oceans Canada, Freshwater Institute
FUNDING SOURCE:	DFO
EXPECTED COMPLETION DATE:	1986
RELEVANT BEMP HYPOTHESIS NUMBER(S):	3, 4, 6

BRIEF PROJECT DESCRIPTION

Aerial surveys were conducted in Amundsen Gulf during the second week of June 1985. Hauled-out seals were counted visually and also photographed for later analysis and comparison with visual estimates. The data from these surveys are not yet analysed.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

The results of this essentially methodological study are relevant to the three hypotheses that address distribution and numbers of ringed seals.

HYPOTHESIS NO. 4

INCREASED FREQUENCY OF ICEBREAKER TRAFFIC THROUGH THE LANDFAST ICE AND THROUGH AMUNDSEN GULF WILL REDUCE RINGED SEAL PUP PRODUCTION AND POPULATION LEVELS

INTRODUCTION

This hypothesis was reworded slightly and one link (Link 4) was added during the 1985 BEMP workshop. Participants at that workshop concluded that direct mortality of ringed seal pups due to icebreaker traffic would be inconsequential. They also conducted that large-scale destabilization of the ice sheet could have significant effects on ringed seal populations, although the evidence for such destabilization is not strong.

NEW INFORMATION

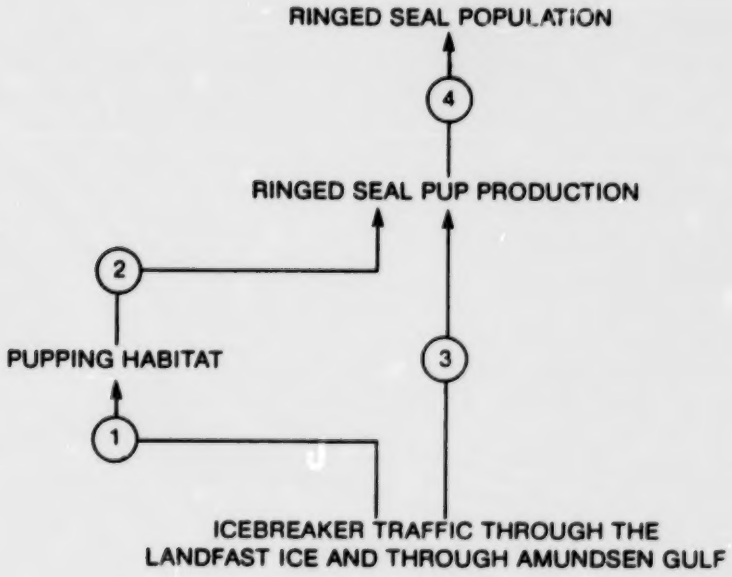
The results of the study assessing effects of icebreaker traffic on the ice regime of Admiralty Inlet (Project Overview 2-2) are particularly relevant to Link 1 of this hypothesis. That study concluded that icebreaker traffic may have advanced break-up by one or two days but that even in the presence of icebreaker traffic, break-up was within the range of normal variability. Several other studies conducted in 1985 have either addressed the use of lairs, including birth lairs, by ringed seals (Project Overviews 3-3 and 3-4) or have provided methodological information potentially relevant to the assessment of this hypothesis (e.g., Project Overviews 1-15, 3-5 and 3-6). The collection of precisely navigated and ice-enhanced imagery resulting from the Institute of Ocean Sciences ice movement study (Project Overview 6-5) may also be of value in studies of ice characteristics relative to ringed seal pupping habitat.

FIGURE 4-1

POTENTIAL EFFECTS OF INCREASED FREQUENCY OF ICEBREAKER TRAFFIC THROUGH THE LANDFAST ICE AND THROUGH AMUNSEN GULF ON RINGED SEAL PUP PRODUCTION AND POPULATION LEVELS

REVISED HYPOTHESIS NO. 4

Increased frequency of icebreaker traffic through the landfast ice and through Amundsen Gulf will reduce ringed seal pup production and population levels



LINKAGES

1. Icebreaking vessels operating in the landfast ice and through Amundsen Gulf will decrease the amount of pupping habitat available for ringed seals.

2. Adequate pupping habitat is necessary for the production of ringed seal pups.

3. Icebreaker traffic in late March, April and May will kill ringed seal pups.

4. Reduced ringed seal pup production will result in lower population levels.

HYPOTHESIS NO. 5

ICEBREAKER TRAFFIC IN THE TRANSITION (SHEAR) ZONE WILL REDUCE BEARDED SEAL PUP PRODUCTION

INTRODUCTION

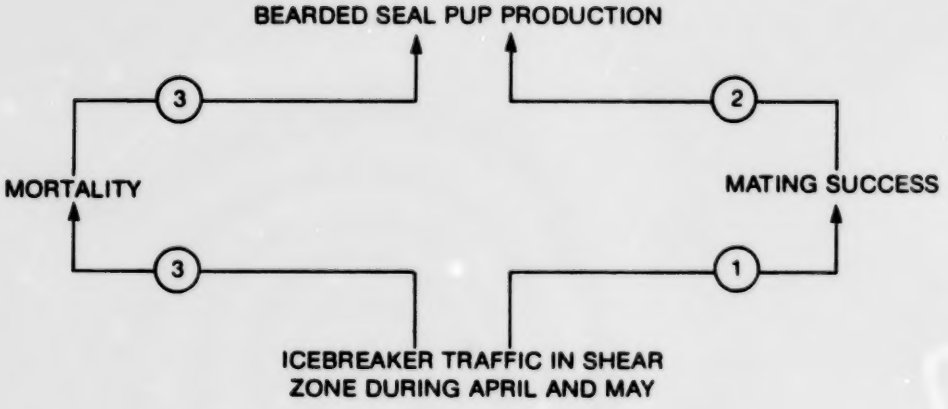
The bearded seal inhabits loose- and broken-ice areas, and breeds on the ice surface within the transition zone of the Beaufort Sea. Since these areas are also likely to be the preferred corridors for shipping traffic, including icebreakers, there is concern that icebreaking activities in this zone during late April to early May will kill some pups. The 1983-84 BEMP workshop concluded that this hypothesis was valid but that effects would be difficult to detect. This conclusion was confirmed at the 1985 BEMP workshop.

No new information directly relevant to any of the linkages of this hypothesis is available. However, some of the remote sensing techniques that are being tested (Project Overview 1-15) may be useful for assessing bearded seal populations.

FIGURE 5-1

POTENTIAL EFFECTS OF ICEBREAKER TRAFFIC IN THE TRANSITION ZONE ON BEARDED SEAL PUP PRODUCTION

Icebreaker traffic in the transition (shear) zone will reduce bearded seal pup production



LINKAGES

1. Icebreaker traffic in the shear zone during April and May will interfere with vocalizations of male bearded seals, and this will result in reduced mating success.

2. Successful mating is necessary for production of bearded seal pups.

3. Icebreaker traffic in the shear zone during April and May will result in mortality of bearded seal pups.

HYPOTHESIS NO. 6

ICEBREAKER TRAFFIC IN AMUNDSEN GULF WILL AFFECT RINGED SEAL AND POLAR BEAR POPULATIONS

INTRODUCTION

The 1983-84 BEMP workshop concluded that the upper links of this hypothesis were probably valid. However, there was insufficient information with which to reach a firm conclusion about the lowest links, particularly Link 1. The 1983-84 workshop also noted that, short of catastrophic changes in ice regime, effects on polar bears and ringed seals would likely be undetectable with present methods. Participants at the 1985 BEMP workshop generally agreed with these conclusions. Additional discussion in 1985 centred around the possibilities that (1) Arctic cod and bowhead whales compete for available zooplankton, and (2) ringed seal populations have increased in response to greater productivity of Arctic cod following the near extirpation of bowheads by commercial whaling. No conclusions regarding these hypotheses were reached.

NEW INFORMATION

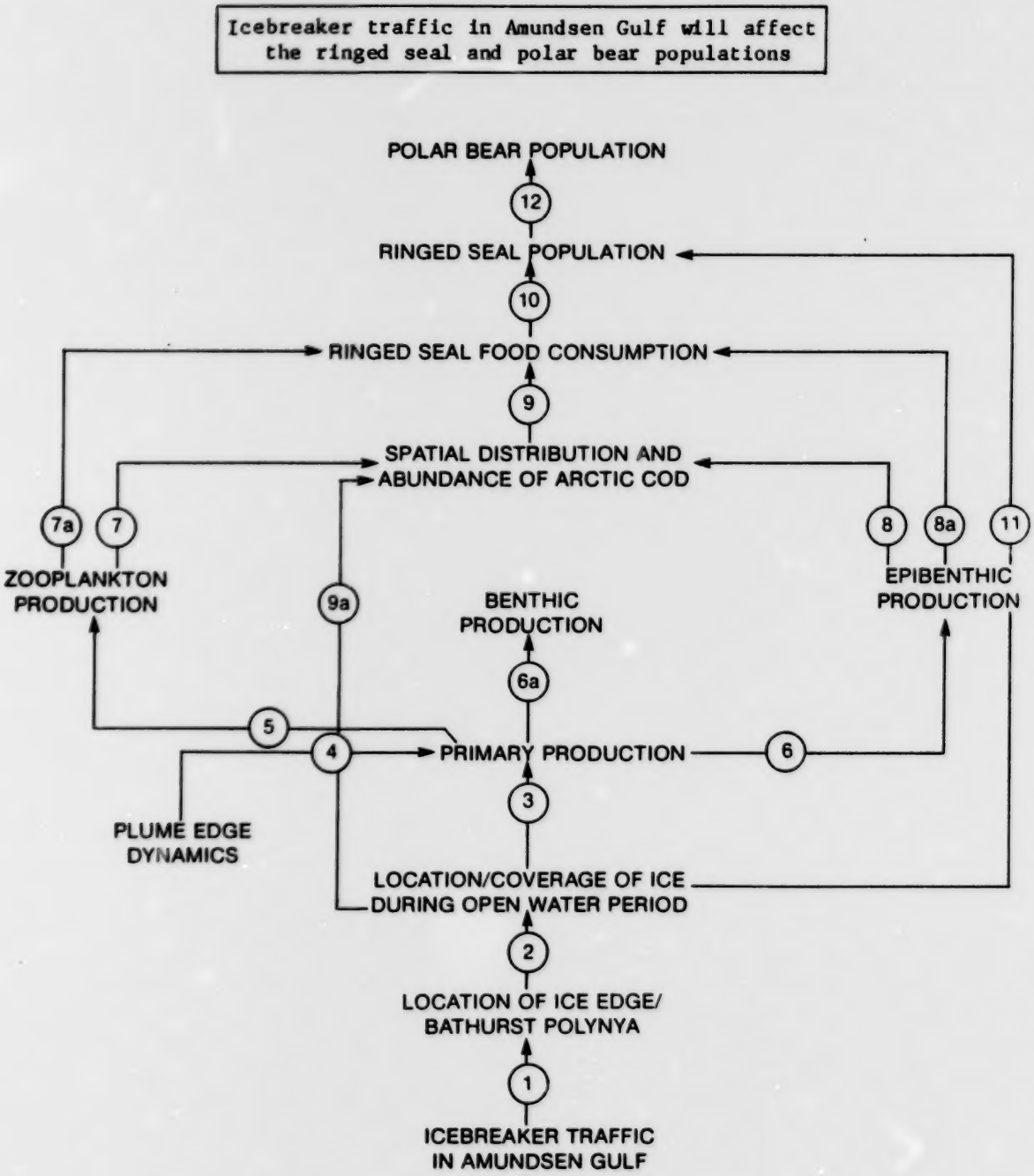
This hypothesis encompasses much of the food web of the Beaufort Sea and, thus, most studies conducted in the Beaufort Sea are relevant to its linkages in one way or another. Nevertheless, a few studies conducted or completed in 1985 are particularly relevant.

For example, the study of interaction between ice regime and icebreakers (Project Overview 2-2) provides the first detailed study of the potential for icebreaking to cause early break-up. The attempt to determine from historic catch records whether two stocks of bowheads existed in the western Arctic (Project Overview 1-10) is relevant to the discussion of possible competition between bowheads and Arctic cod. If there were, indeed, two stocks, one extinct and the other still extant and using the Beaufort Sea in good numbers, then the argument that Arctic cod production has increased during this century would be weakened.

Other studies that are relevant of this hypothesis include four studies relating to food chain linkages and two physical studies. Three of the food chain studies (Project Overviews 3-2, 6-1 and 6-2) were discussed at the 1985 workshop and one is new. Fisheries and Oceans Canada will begin a study in 1986 to assess the distribution and biomass of Arctic cod in the Beaufort Sea (Project Overview 6-3). The two physical studies (Project Overviews 6-4 and 6-5) both provide information relating to nutrient transport in the Beaufort Sea.

FIGURE 6-1

POTENTIAL EFFECTS OF ICEBREAKER TRAFFIC IN AMUNDSEN GULF ON THE RINGED SEAL AND POLAR BEAR POPULATIONS



LINKAGES

1. Icebreaker traffic in Amundsen Gulf will move the stable ice edge to the east (and alter the Bathurst polynya) in winter and spring.

2. Movement of the stable ice edge may in turn change the total amount of open water in the region.

3. The coverage thickness and location of ice determine the level of primary productivity.

4. Primary production is enhanced (perhaps in patches) near the Mackenzie River plume edge.

5, 6 and 6a The level of primary productivity determines the level of secondary productivity in zooplankton, epibenthos and benthos.

7, 8 and 9a Distribution and production of zooplankton and epibenths and the location of ice determine the production and distribution of Arctic cod.

10. Quality and quantity of food determine ringed seal survival and mortality.

11. Location and type of ice are important in determining ringed seal distribution.

12. Numbers of polar bears are determined by numbers of ringed seals.

BEMP PROJECT OVERVIEW NO. 6-1

TITLE:	Study of Arctic cod and its importance in arctic food chains
PRINCIPAL INVESTIGATORS:	M.S.W. Bradstreet, A.D. Sekerak
AFFILIATION:	LGL Ltd., King City, Ontario
FUNDING SOURCE:	DSS, DFO, INAC
EXPECTED COMPLETION DATE:	Complete
RELEVANT BEMP HYPOTHESIS NUMBER(S):	6, and of general interest

BRIEF PROJECT DESCRIPTION

The primary goal of this study was to use existing biological material and samples to obtain new information on the ecology of Arctic cod and its importance to seabird and marine mammal populations. Existing specimens of Arctic cod, especially samples of cod or their otoliths obtained from the stomach of various predators (white whale, ringed seal, harp seal, narwhal, fulmar, thick-billed murre, kittiwake, etc.), were examined during the course of this project. Samples originated from the Chukchi Sea, Beaufort Sea, central High Arctic, Baffin Bay and Labrador Sea. The majority of samples were from areas east of the Beaufort Sea.

The study concluded that:

1. Arctic cod otoliths provide a more accurate mechanism for aging than do scales;

2. one hyaline layer is laid down in the otolith per year;

3. there were significant differences among sampling regions in growth patterns of Arctic cod;

4. otoliths from predator stomachs and faeces showed few differences in age distribution due to age of the predator or the amount of food in its stomach, or due to the habitat, area, year or season in which the predator was collected;

5. when samples were grouped, large-scale geographical and temporal differences in age-frequency distribution of otoliths were apparent;

6. patterns of mortality were typical of fish populations that are not exploited by man;

7. mortality increases with age after 3 yr; and

8. as evidenced by the distribution and diets of harp seals, narwhals and white whales in the eastern Arctic, Arctic cod undergo a major inshore movement in late summer. Distribution and diet of ringed seals, however, indicates that Arctic cod occur throughout much of the eastern Canadian Arctic on a year-round basis.

The authors of this study point out that some analyses were constrained because the samples were not collected in order to study the cod themselves but rather were obtained during studies of cod predators. The authors recommend systematic collections of ringed seals, which are widespread and seem to feed on Arctic cod wherever they are present, to provide the basis for a sampling program designed specifically to study Arctic cod.

RELATIONSHIP AND RELEVANCE TO BEAUFORT ENVIRONMENTAL MONITORING PROJECT

Research on Arctic cod and the role of this species in the diets of its predators is relevant to any impact hypothesis that involves either direct or indirect linkages (through trophic relationships) between industrial development activities and key species of marine mammals or seabirds. Any improvement in our understanding of the general processes that govern the distribution and abundance of Arctic cod and their availability to predators will increase our ability to design adequate environmental monitoring programs to accompany hydrocarbon development in the Beaufort Sea.

BEMP PROJECT OVERVIEW NO. 6-2

TITLE:	Mackenzie shelf fisheries habitat research
PRINCIPAL INVESTIGATORS:	M. Lawrence, L. deMarch
AFFILIATION:	Fisheries and Oceans Canada, Freshwater Institute
FUNDING SOURCE:	DFO, NOGAP
EXPECTED COMPLETION DATE:	1988
RELEVANT BEMP HYPOTHESIS NUMBER(S):	6, 19, and of general interest

BRIEF PROJECT DESCRIPTION

The planning for this study was reported as 1985 BEMP Project Overview No. 30. During 1985 two other projects (1985 BEMP Project Overview 17, Fish feeding ecology; and BEMP Project Overview 23, The biological importance of Tuk Harbour to fish) became part of the overall fish habitat investigation.

The major objectives of this investigation are:

1. to identify, in both spatial and temporal terms, the areas of the Mackenzie shelf from Demarcation Pt. to Cape Bathurst that are of significance to estuarine and marine fish;

2. to characterize areas of important or critical marine habitats in terms of their physical-chemical environment, biotic community structure or production; and

3. to characterize the feeding habits of pelagic and demersal fish species of the Mackenzie Shelf in relation to habitat and season (open water vs. ice cover).

Data analysis for this project is ongoing.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

The results of this study will provide basic descriptive information on biological communities of the Mackenzie Shelf and will contribute to an increased understanding of energy flow in the Beaufort Sea and the trophic relationships among components of the system.

The study is relevant to Links 7, 8 and 9a of Hypothesis 6. These links assume that a reduction in zooplankton and epibenthos (prey of Arctic cod) will result in reduced numbers or size of cod, and that this in turn will reduce the population of ringed seals.

This study may also provide insight into trophic relationships relevant to Hypothesis 19, 'Dredging and deposition of spoils will reduce the bearded seal population'. This could presumably occur indirectly as a result of dredging-related reductions in the benthic prey organisms of some fish species, which could then result in fewer and smaller fish being available for bearded seal consumption. The present studies on the feeding habits of fish will lead to a better understanding of the plausibility of such a functional relationship.

BEMP PROJECT OVERVIEW NO. 6-3

TITLE: Distribution and abundance of Arctic cod
PRINCIPAL INVESTIGATOR: R. Crawford
AFFILIATION: Fisheries and Oceans Canada, Freshwater Institute
RELEVANT BEMP HYPOTHESIS NUMBER(S): 6

BRIEF PROJECT DESCRIPTION

This study of the distribution, abundance and vulnerability to industrial activities of Arctic cod has been carried out during the past two seasons at Resolute Bay. In 1986 work will continue near Resolute Bay with attempts to compare movements of Arctic cod and marine mammals. In 1986 sampling will also begin in the Beaufort Sea. Hydro-acoustic methods will be used to obtain data on abundance and biomass of Arctic cod and other species in the Beaufort Sea.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

Research on Arctic cod and the role of this species in the diets of its predators is relevant to any impact hypothesis that involves either direct or indirect linkages (through trophic relationships) between industrial development activities and key species of marine mammals or seabirds. This study is particularly relevant to Hypothesis 6 since information may be obtained on spatial and temporal patterns in the abundance and distribution of arctic cod which in turn affect ringed seal food consumption (Link 9 of Hypothesis 6), seal population dynamics and therefore polar bear populations.

BEMP PROJECT OVERVIEW NO. 6-4

TITLE:	Wintertime thermohaline circulation in the Beaufort Sea
PRINCIPAL INVESTIGATOR:	H. Melling
AFFILIATION:	Institute of Ocean Sciences, Sidney, B.C.
FUNDING SOURCE:	DFO
EXPECTED COMPLETION DATE:	1986
RELEVANT BEMP HYPOTHESIS NUMBER(S):	6, of general interest

BRIEF PROJECT DESCRIPTION

This study was initiated in 1981 with the objective of improving understanding of the cross-shelf circulation driven by wintertime freezing in the Beaufort Sea. An extensive regional survey of temperature and salinity profiles was conducted, with emphasis on the outer shelf and continental slope. Current measurements from three moorings near the 100-m isobath, and ice-drift data were obtained. The observational program was repeated, with some variation, in 1985. In particular, profiles of dissolved silicate and nitrate were acquired in 1985.

The data from 1981 have provided an excellent description of a strong haline frontal structure over the outer shelf. These data, in conjunction with the current and drift measurements, have allowed a better formulation of the dynamics controlling the frontal characteristics, and also the exchanges of fluid and fluid properties between shelf and basin. The freezing rate over the shelf, the long-shelf pressure gradient, and diapycnal mixing appear to be the important factors, while the total significance of cross-shelf Ekman flows is not yet clear. The reasons for a much reduced presence of freezing-associated waters in the Beaufort Sea in 1985 have yet to be clarified.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

The re-supply of nutrient-rich waters to the Mackenzie shelf apparently occurs in autumn and winter, both through regeneration of nutrients from sediment and through exchange with nutrient-enriched waters in the basin to the north. This study, though directed at understanding of the salt budget, will provide insight into that part of the shelf-basin exchange driven by thermohaline influences. The availability of nutrients is one factor determining primary productivity and, thus, food supply for upper trophic levels in the Beaufort Sea.

BEMP PROJECT OVERVIEW NO. 6-5

TITLE:	Beaufort Sea ice movement program
PRINCIPAL INVESTIGATORS:	H. Melling, P. Budgell, J. Cherniawsky
AFFILIATION:	Institute of Ocean Sciences, Sidney, B.C.; G.A. Borstad Ltd., Sidney, B.C.
FUNDING SOURCE:	OERD and DFO
EXPECTED COMPLETION DATE:	1989
RELEVANT BEMP HYPOTHESIS NUMBER(S):	4, 6

BRIEF PROJECT DESCRIPTION

This is a program comprising a number of studies with the overall objective of improving understanding of the dynamics of pack ice movement, in the expectation of improving short-term (<3 days) predictions of ice drift. The approach is two-faceted. An initiative based on numerical modelling is progressing through a hierarchy of models developed to address specific issues in a diagnostic sense. At present, effort is focused on a barotropic model covering the ocean south of 74°N and extending from Dolphin and Union Strait to beyond Point Barrow. Direct wind forcing of the ocean, the generation of propagating periodic disturbances, their scattering from topographic irregularities, and the effects of and on idealized ice covers are being studied.

The second facet is observational. At present, a year-long set of currents and ice movements is being acquired that can be applied to the study of time-varying and steady (the regional circulation) flow features of large (>100 km) along-shelf scale. Since this project is concerned with predictability, the fraction of the flow variance represented by these features (whose prediction may be tractable) in an important number to be determined empirically. A major component of the present data collection effort is an array of 16 instrument chains (40 instruments measuring current, temperature, salinity, sea level) which has been recording data in the southern Beaufort since March 1985. Recovery is anticipated in 1986. Concurrent with subsurface measurements, selected digital AVHRR images are being rectified, navigated and enhanced to enable characterization of ice cover throughout the year, and determination of its movement whenever sequences of daily images are available. With these observations, the inter-relationship between ice and ocean movements can be studied.

Results from empirical observations are not yet available. Modelling studies to date have served to elucidate the relative significance of wind forcing and of potential-vorticity conservation in determining oceanic flow. During strong winds a coastal boundary layer extending to the 30-m isobath is produced, wherein flow is frictionally controlled. Over the shelf, strong winds serve to suppress flow features of small horizontal scale. After storms pass, however, the directly forced flow dissipates and circulation is steered by topographic irregularities and dominated by eastward propagating shelf waves. Herschel Canyon scatters long-wave energy moving from the west into shorter waves. Near Cape Bathurst, the abrupt narrowing of the shelf creates a cyclonic circulation cell in the mouth of Amundsen Gulf.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

The re-supply of nutrient-rich waters to the Mackenzie shelf apparently occurs in autumn and winter, both through regeneration of nutrients from sediment and through exchange with nutrient-enriched waters in the basin to the north. This study will provide a much improved understanding of regional circulation in the Beaufort Sea, and insight into that part of the shelf-basin exchange driven by the joint effects of wind and sea floor topography. The availability of nutrients is one factor determining primary productivity and thus food supply to higher trophic levels. In addition, the collection of precisely navigated and ice-enhanced imagery accumulated in this project could be of use to studies of ice relevant to assessment of ringed seal pupping habitat (Hypothesis 4, Link 2).

HYPOTHESIS NO. 7

THE PRESENCE OF ACTIVE FACILITIES WILL RESULT IN INCREASED POLAR BEAR MORTALITY

INTRODUCTION

Participants at the 1985 BEMP workshop confirmed the overall validity of this hypothesis. Although not all bears that encounter offshore facilities are expected to be attracted to the facilities, bears that are attracted may be killed. This mortality is of concern since the present Inuit harvest of polar bears, which is regulated by quota, is believed to be at the maximum sustainable level. Increased mortality at offshore facilities could result in the necessity to reduce harvest quotas. The 1985 BEMP workshop recommended continuation of research into methods of detection and deterrence of polar bears.

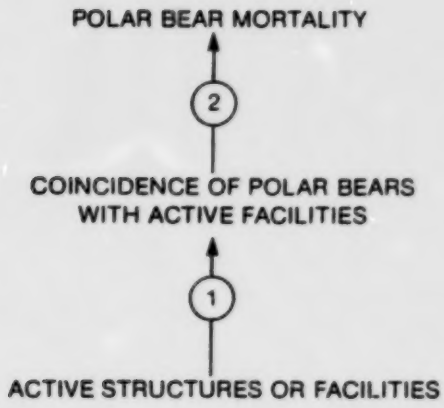
NEW INFORMATION

Deterrent research was carried out by the government of the Northwest Territories in 1985 (Project Overview 7-1). In addition, further information was obtained that tends to confirm that polar bears in the Canadian and American portions of the Beaufort Sea are one population (Project Overview 7-2). Finally, a new study that will assess changes in various parameters of the polar bear population in the Canadian Beaufort Sea since the 1970's has been initiated (Project Overview 7-3).

FIGURE 7-1

POTENTIAL EFFECTS OF ACTIVE FACILITIES ON POLAR BEARS

The presence of active facilities will result in increased polar bear mortality



LINKAGES

1. Polar bears will encounter active structures or facilities.

2. Polar bears that approach offshore structures have to be controlled; this will result in the need to destroy some bears.

BEMP PROJECT OVERVIEW NO. 7-1

TITLE:	Bear deterrent research program
PRINCIPAL INVESTIGATOR:	P. Clarkson
AFFILIATION:	GNWT Renewable Resources, Yellowknife
FUNDING SOURCE:	Various government and industry sources
EXPECTED COMPLETION DATE:	Ongoing
RELEVANT BEMP HYPOTHESIS NUMBER(S):	7

BRIEF PROJECT DESCRIPTION

The general purpose of this research program is to develop successful techniques for deterring bears from sites of human habitation in order to increase human safety and reduce the number of nuisance bear kills. The program has been ongoing since 1981.

Development of a bear deterrent and detection training and education program began in 1984. In 1985 a 'safety in bear country' manual designed for the use of personnel charged with the responsibility of protecting others from bear incidents was produced. The manual covers subjects including camp design and maintenance, detection and deterrent systems, appropriate firearms for bear control, bear biology and a list of suppliers for detection and deterrent devices. In addition to the manual, a one-day workshop for those casually involved with travel in bear country (e.g., boy scout leaders) and a two-day workshop for those regularly involved with bear problems (e.g., industry camp foremen) have been designed and implemented. A third workshop that is used to train instructors for the above-mentioned workshops has also been produced.

Research on deterrent techniques included tests of three types of projectiles, tests of acoustic deterrents at frequencies from 0.5 kHz to 12.5 kHz, and tests of two types of portable electric fences. Acoustic deterrents were not effective at any frequency and the the electric fences were not effective, largely because the support poles used were inappropriate for the terrain where they were tested. The fences will be tested again in 1986. The three projectiles tested were Cart-a-ball, a rubber ball fired from a 12-gauge shotgun; Ferrt slugs, also fired from a 12-gauge shotgun; and Bear Thumper, a 31-mm slug fired from a specially designed gun. All successfully deterred bears but the Cart-a-ball was too inaccurate to be recommended for general use. Further tests of these devices will be conducted in 1986.

RELATIONSHIP AND RELEVANCE TO BEAUFORT ENVIRONMENTAL MONITORING PROJECT

Hypothesis 7 states that 'The presence of active facilities will result in increased polar bear mortality'. The two links of this hypothesis suggest that polar bears will be attracted to offshore structures and the need to maintain worker safety would then necessitate the destruction of some animals. The 1983-84 BEMP report recommended support of ongoing deterrent research programs. This mitigation research program is consistent with the BEMP recommendation and is expected to minimize the need to kill nuisance bears (Link 2).

BEMP PROJECT OVERVIEW NO. 7-2

TITLE: Research on polar bears in Alaska
PRINCIPAL INVESTIGATOR: S. Amstrup
AFFILIATION: U.S. Fish and Wildlife Service
EXPECTED COMPLETION DATE: Ongoing
RELEVANT BEMP HYPOTHESIS NUMBER(S): 7

BRIEF PROJECT DESCRIPTION

The U.S. Fish and Wildlife Service is presently responsible for the conservation and management of polar bears in the United States. The Alaskan polar bear research program was initiated to assist with this mandate. The principal objectives of the research program are to determine: (1) the size of Alaskan polar bear populations; (2) movements and distribution patterns; and (3) maternity denning areas. Research on Alaskan bears has been ongoing since 1966. During the period from fall 1983 to fall 1984, in cooperation with the GNWT Wildlife Service, research also extended into the Canadian Beaufort region. This research involved mark-recapture procedures and radio-telemetry.

The mark-recapture and telemetry studies indicate that the bears in the Cape Bathurst to Point Barrow area are all members of one breeding population. Individual bears have been tracked throughout this area during the winter but often show seasonal fidelity to general positions of the area. Most maternity dens found have been on the sea ice.

The size of the Beaufort Sea population has been estimated by two mark-recapture methods and by two methods based on sightings per hour of flight. These methods all suggest a population size of about 1800 bears. The population is believed to be stable.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This research provides information that is indirectly relevant to Hypothesis 7. The results of the Alaskan research are significant because they show that the Beaufort Sea polar bear population extends from Point Barrow to near Cape Bathurst. Therefore, any activity in Alaska that adversely affects this population could lead to reduced numbers of bears in the Canadian Beaufort (hence a reduced harvest), and perhaps then to the perception that reduced harvest was due to offshore hydrocarbon development in the Canadian Beaufort. Although polar bear harvests are regulated in Canada, this is not the case in the U.S. There is presently a concern in Alaska that the unregulated subsistence harvest of polar bears is concentrating on female bears and cubs (which tend to use nearshore areas) to such an extent that it may begin to adversely affect the population if the harvest were to increase further.

BEMP PROJECT OVERVIEW NO. 7-3

TITLE: Assessment of the Beaufort Sea polar bear population
PRINCIPAL INVESTIGATOR: I. Stirling
AFFILIATION: Canadian Wildlife Service
EXPECTED COMPLETION DATE: 1988
RELEVANT BEMP HYPOTHESIS NUMBER(S): 7, 9

BRIEF PROJECT DESCRIPTION

The objective of this study is to compare the population size, distribution of subpopulations, and demographic and reproductive parameters of the polar bear population in the Beaufort Sea in 1986-88 to the results of a similar study conducted from 1971-79. An attempt will be made to evaluate whether or not the last ten years of offshore exploration for hydrocarbons have had any detectable effects (positive or negative) on the polar bear population. In 1985, 180 polar bears were captured, tagged, measured and had a premolar tooth collected for age determination. Analysis of the data is underway.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This project will provide background information that is of relevance to all hypotheses concerning polar bears. Detection of changes in the size or demography of the polar bear population, especially if related to hydrocarbon development, would have clear relevance to Hypothesis 7. If the polar bear population were found to be declining, quotas would likely be reduced and fewer bears would be available for harvesting. Since many bears will be examined during this project, the project may also provide information about oiled bears relevant to Hypothesis 9, "Chronic/episodic oil spills resulting from normal hydrocarbon development activities within and adjacent to the marine environment will result in localized mortality of polar bears".

HYPOTHESIS NO. 8

OFFSHORE DEVELOPMENT ACTIVITIES WILL REDUCE THE HARVEST OF POLAR BEARS

INTRODUCTION

This hypothesis focuses on access to bears. The hypothesis suggests that offshore development will produce physical barriers to Inuk hunters or will cause bears to move offshore where they will be inaccessible to hunters. Participants at both the 1983-84 and 1985 workshops concluded that the hypothesis was unlikely and did not warrant research or monitoring. The only recent work relevant to this hypothesis was the study of the effects of an icebreaker on hunter travel in Admiralty Inlet (Project Overview 2-2). The results of this study were discussed during the 1985 BEMP workshop.

FIGURE 8-1

POTENTIAL EFFECTS OF OFFSHORE DEVELOPMENT ON POLAR BEAR HARVEST

LINKAGES

1. Hunter access to polar bears will be reduced because offshore development will cause bears to move farther offshore and/or create physical barriers to Inuit travel on the ice.

2. Reduced access to polar bears will lead to reductions in the Inuit harvest of polar bears.

HYPOTHESIS NO. 9

CHRONIC/EPISODIC OIL SPILLS RESULTING FROM NORMAL HYDROCARBON DEVELOPMENT ACTIVITIES WITHIN AND ADJACENT TO THE MARINE ENVIRONMENT WILL RESULT IN LOCALIZED MORTALITY OF POLAR BEARS

INTRODUCTION

Participants at the 1985 BEMP workshop agreed with the formulation of both the linkages and the overall statement of this hypothesis. They also agreed that the hypothesis was valid.

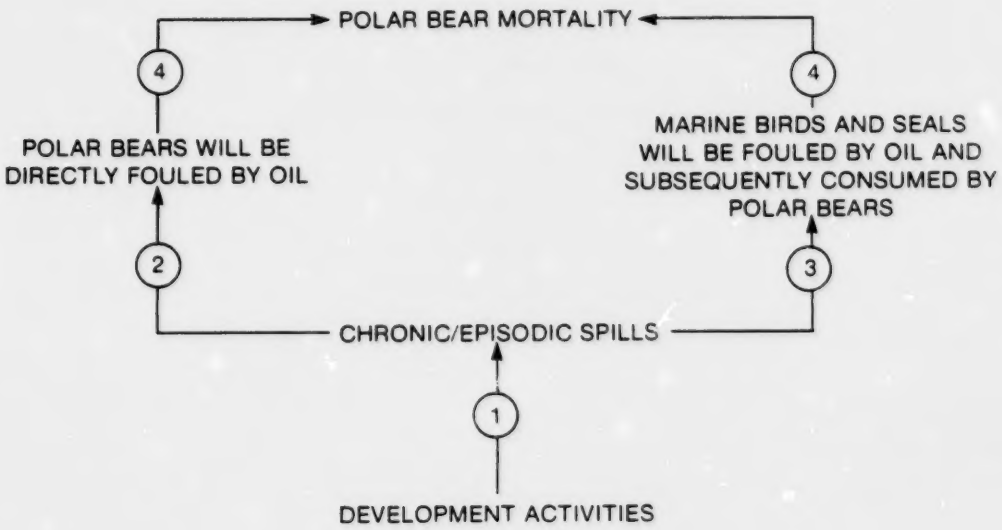
NEW INFORMATION

Little new information relating directly to this hypothesis is available. The results of studies on interactions of oil and ice (Project Overview 9-1) may provide information relevant to assessing the vulnerability of polar bears to spilled oil. In addition, the study described in Project Overview 7-3 will entail capturing and marking a large number of bears. Records will be kept of oil (if any) on each bear captured.

FIGURE 9-1

POTENTIAL EFFECTS OF CHRONIC/EPISODIC OIL SPILLS RESULTING FROM NORMAL PETROLEUM HYDROCARBON DEVELOPMENT ACTIVITIES WITHIN AND ADJACENT TO THE MARINE ENVIRONMENT ON POLAR BEARS

Chronic/episodic oil spills resulting from normal petroleum hydrocarbon development activities within and adjacent to the marine environment will result in localized mortality of bears



LINKAGES

1. Development activities will result in chronic/episodic spills.

2. Chronic spills will result in the direct fouling of polar bears.

3. Chronic spills will result in the direct fouling of marine birds and seals that are consumed by bears.

4. Mortality of bears will occur if oil is contacted or ingested.

BEMP PROJECT OVERVIEW NO. 9-1

TITLE:	The behaviour of oil in ice: effect of ice dynamics
PRINCIPAL INVESTIGATOR:	D.F. Dickins
AFFILIATION:	D.F. Dickins Engineering, Vancouver, B.C.
FUNDING SOURCE:	Environmental Protection Service
EXPECTED COMPLETION DATE:	Complete
RELEVANT BEMP HYPOTHESIS NUMBER(S):	9, 10

TITLE:	Experimental oil spills in east coast waters
PRINCIPAL INVESTIGATORS:	I. Buist; D.F. Dickins
AFFILIATION:	S.R. Ross Environmental Research Ltd., Ottawa; D.F. Dickins Engineering, Vancouver, B.C.
FUNDING SOURCE:	ESRF
EXPECTED COMPLETION DATE:	August 1986
RELEVANT BEMP HYPOTHESIS NUMBER(S):	9, 10

BRIEF PROJECT DESCRIPTION

The underlying objective of both studies was to provide an improved understanding of the behaviour and fate of oil in pack ice. In the EPS study, now completed, dynamic sea ice processes affecting oil behaviour in moving pack ice environments were examined for the Beaufort Sea, Lancaster Sound and offshore Labrador regions. The results were derived from Landsat satellite and Side Looking Airborne Radar (SLAR) imagery involving data from 702 ice floes and 255 leads.

Lead motion statistics reveal that the ice cover of the Beaufort Sea can be characterized as a zone of expanding or divergent movements. Lead closures were observed in only 17% of the documented events. Maximum measured rates of expansion and contraction were 17 and 3 km/day, respectively. At the average recorded rates of less than 20 m/hour, a lead of typical width (30 m) would take over one hour to close completely. Fewer than 30% of the floes moved at speeds of 10 km/day or more. The largest ice floe velocities were observed in Amundsen Gulf. Based on limited measurements of offshore pack ice thickness available in the Beaufort Sea, a range of values of ice freeboard was tabulated. A typical value of ice freeboard from the Beaufort Sea region is approximately 15 cm. Complete results are available in a report prepared for the Environmental Protection Service (EPS report number EE62).

The ongoing ESRF research program involves experimental crude oil spills in Canadian east coast pack ice. After considerable delay, the experimental studies are now planned for March 1986. Data necessary to determine the physical and chemical interactions of crude oil with moving ice will be collected during the course of these experiments.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

Both of these studies provide information on variability in the properties of oil in pack ice areas as a function of location, time of year, pack ice concentration and weather conditions. The results of these studies are expected to be relevant to Hypotheses 9 and 10, which focus on the possible mortality of polar bears and seabirds as a result of chronic oil spills near offshore structures. Additional information on factors affecting the spatial and temporal distribution and physical-chemical properties of oil in pack ice areas is expected to be of particular value in determining the potential susceptibility of polar bears and seabirds to oil exposure. Both of these resource groups are already known to be very sensitive to oil exposure.

HYPOTHESIS NO. 10

CHRONIC (EPISODIC) OIL SPILLS RESULTING FROM NORMAL HYDROCARBON DEVELOPMENT ACTIVITIES WITHIN AND ADJACENT TO THE MARINE ENVIRONMENT WILL RESULT IN LOCAL MORTALITY OF CERTAIN SPECIES OF BIRDS

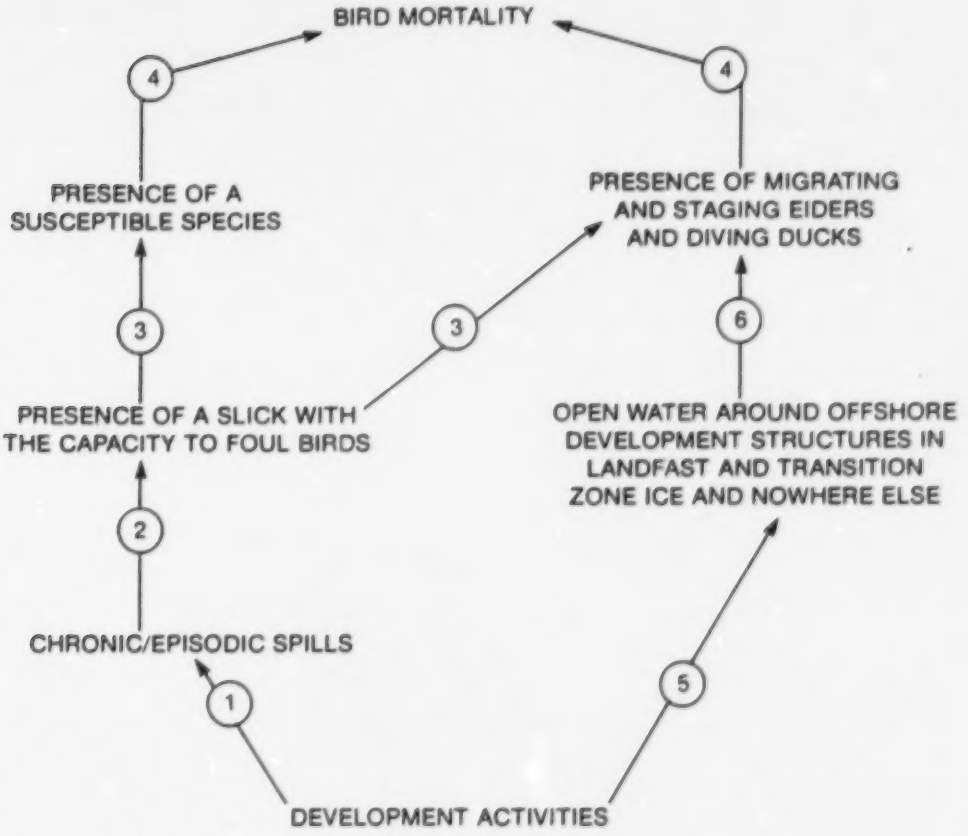
INTRODUCTION

After some discussion, participants at the 1985 BEMP workshop concluded that Hypotheses 10 and 11 from the 1983-84 BEMP report should be combined as the present Hypothesis 10. The subgroup noted that Hypothesis No. 11 was a special case of Hypothesis No. 10, and therefore, could be included as part of the more general hypothesis. In addition, the number of links was reduced to eliminate the need for repetitive discussion of invalid or improbable linkages in future BEMP workshops. New information relevant to this hypothesis comes from physical studies that describe processes that could influence the fate of spilled oil (Project Overviews 9-1, 10-1 and 15-3) and are, therefore, relevant to assessment of the probability that birds will encounter oil.

FIGURE 10-1

POTENTIAL EFFECTS OF CHRONIC (EPISODIC) OIL SPILLS RESULTING FROM NORMAL PETROLEUM DEVELOPMENT ACTIVITIES ON BIRDS

Chronic (Episodic) oil spills resulting from normal petroleum hydrocarbon development activities within and adjacent to the marine environment will result in local mortality of certain species of birds.



LINKAGES

1. Development activities will result in chronic (episodic) spills of petroleum hydrocarbons.

2. Where chronic (episodic) spills occur, slicks with the capacity to foul birds will be present under certain conditions.

3. Susceptible bird species will co-occur in space and time with the presence of a slick.

4. Mortality of birds will occur following slick contact.

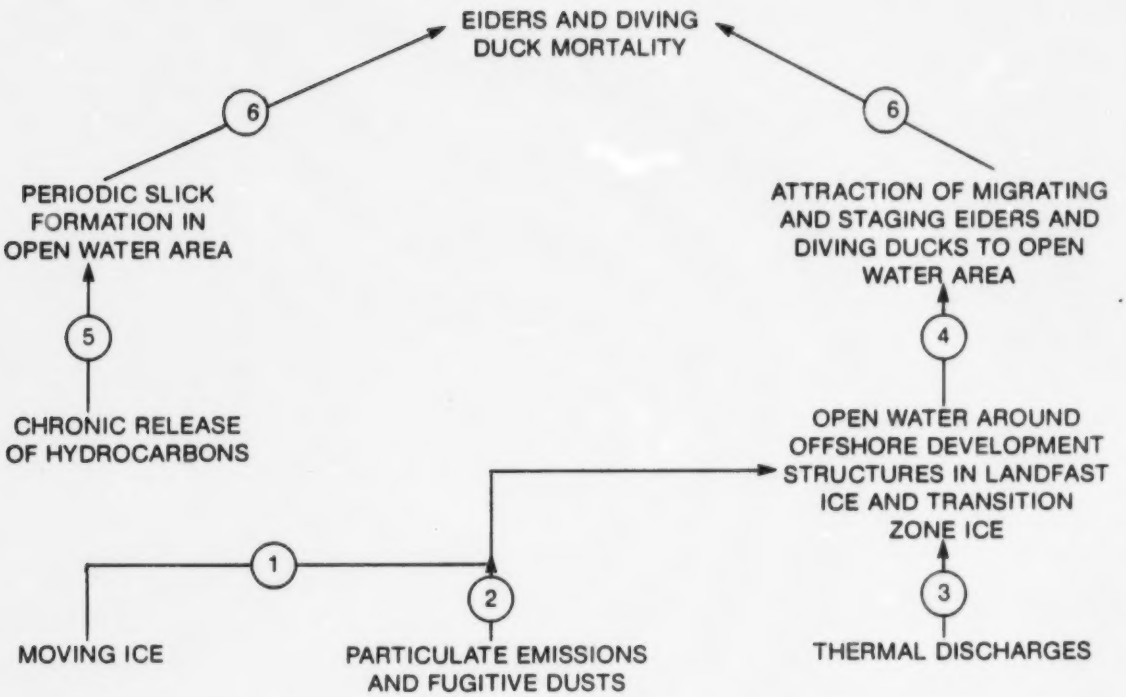
5. Thermal discharges under or onto the ice from offshore production facilities will enhance melting and formation of open water around structures (Hypothesis No. 11, Link 3, 1983-84 BEMP report).

6. Eiders and other diving ducks are attracted to open water areas during migration and staging (Hypothesis No. 11, Link 4, 1983-84 BEMP report).

FIGURE 10-2

POTENTIAL EFFECTS OF OIL NEAR OFFSHORE PLATFORMS ON EIDERS AND DIVING DUCKS

Oil slicks in open water areas around offshore structures during normal periods of ice cover will cause increased mortality of eiders and diving ducks



LINKAGES

1. Moving ice causes rubble fields and open water in the ice surrounding offshore structures.

2. Particulate emissions and fugitive dust will decrease the albedo (increase heat absorption) of the ice, leading to increased melting and earlier formation of open water areas around offshore structures.

3. Thermal discharges under or onto the ice from offshore production facilities will enhance melting and formation of open water around structures.

4. Eiders and diving ducks are attracted to open water areas during migration and staging.

5. Chronic releases of hydrocarbons from offshore structures will cause the periodic formation of oil slicks in open water area.

6. Oiling of birds present in open waters around offshore structures will cause mortality.

BEMP PROJECT OVERVIEW NO. 10-1

TITLE:	Canadian Beaufort Sea physical shore zone analysis
PRINCIPAL INVESTIGATOR:	J. Harper
AFFILIATION:	Dobrocky Seatech Ltd.
FUNDING SOURCE:	NOGAP
EXPECTED COMPLETION DATE:	November 1985
RELEVANT BEMP HYPOTHESIS NUMBER(S):	10, 13, of general interest

TITLE:	Field surveys of log debris lines in the Tuktoyaktuk vicinity: implications to storm surge evaluation
PRINCIPAL INVESTIGATOR:	J. Harper
AFFILIATION:	Dobrocky Seatech Ltd.
FUNDING SOURCE:	DFO; Water Resources Division, DIAND
	October 1985
RELEVANT BEMP HYPOTHESIS NUMBER(S):	10, 13, of general interest

BRIEF PROJECT DESCRIPTION

The objective of the NOGAP study was to provide an analysis and summary of coastal morphology, coastal stability, and coastal processes for the coastline of the Beaufort Sea from the Alaskan border to the Baillie Islands.

Coastal morphology was examined through the use of (1) existing videotapes of the coastline obtained from aircraft overflights and (2) available aerial photography. The coastline was characterized by six distinct coastal morphological types. The dominance of erosional processes was apparent over much of the study area.

Coastal stability was determined through comparisons of aerial photographs obtained in the 1950's and 1970's. Throughout the study area, coastline retreat rates of 1 m/year were typical. In the Mackenzie Delta, the coastline retreat was larger, typically 2 m/year with a maximum value of 18 m/year.

The results of the coastal morphology and coastal stability components of the study were used to interpret and discuss the coastal processes of greatest importance throughout the region. It was suggested that a rise in relative sea level combined with the melting of ice of terrestrial origin were important in explaining the changes in coastal features.

In the DFO/DIAND study, measurements of the elevation of log debris lines were obtained during the summer of 1985. The elevations of debris lines were surveyed at 10 sites in the vicinity of Tuktoyaktuk, relative to the Canadian Hydrographic Service datum level. From the measured elevation, maximum surge elevations of 2 to 3 m were inferred. This maximum surge value was considered to be representative over a return period of at least 50 years. At the more exposed sites, the elevations were larger with values of up to 3.4 m; the larger elevations result from the effect of wave swash in addition to the storm surge.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

Hypotheses 10 and 13 describe a possible mechanism for environmental effects associated with chronic oil spills and releases of hydrocarbons and heavy metals from shorebases and shallow water production facilities. In the former hypothesis, the Valued Ecosystem Components are bird populations that may contact surface oil slicks either directly following spills or due to subsequent release of oil trapped in nearshore sediments. In Hypothesis No. 13, the VEC is fish harvest which could be reduced as a result of hydrocarbon tainting (or perception of same) and the uptake of trace minerals. The research programs described in this overview will provide information regarding the possible fate and dispersal of released oil and other contaminants along the Beaufort Sea coast.

HYPOTHESIS NO. 13

SHOREBASES AND SHALLOW WATER PRODUCTION FACILITIES WILL RELEASE HYDROCARBONS AND HEAVY METALS AT SUFFICIENT LEVELS SUCH THAT FISH HARVEST WILL BE REDUCED THROUGH TAINTING AND HEAVY METAL ACCUMULATIONS

INTRODUCTION

The potential for tainting of fish is of concern because of (1) the existing and possible expansion of use of fish by human populations, and (2) experiences associated with tainting and perceived tainting in the Canadian North and elsewhere in the world. Participants at the 1985 BEMP workshop confirmed that this hypothesis was valid and that tainting of fish was an area of high profile with respect to BEMP.

NEW INFORMATION

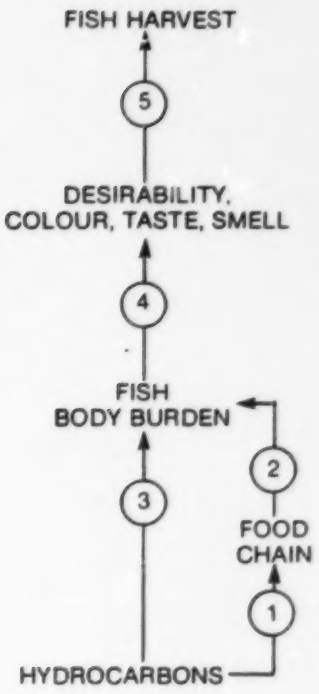
The study that is most relevant to this hypothesis was briefly discussed in 1985 and is now complete (Project Overview 13-1). This study compiled existing information on cases of tainting or perceived tainting and assessed various techniques for determining whether a taint had occurred. In another study, presence of heavy metals and other contaminants in marine fish from various arctic locations, including locations in the Beaufort Sea, were determined (Project Overview 13-2). Studies of indirect relevance to this hypothesis include two studies of physical processes that provide insight into the potential for movement of oil or heavy metals in sediments (Project Overviews 9-1, 10-1 and 15-3).

FIGURE 13-1

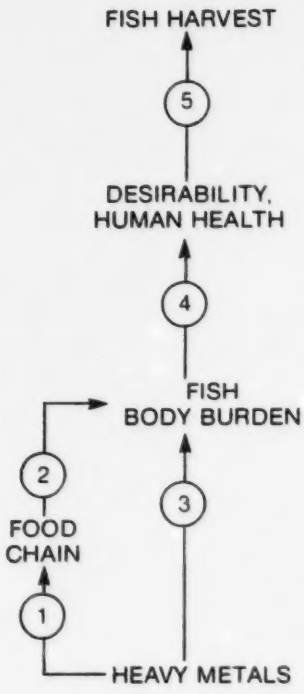
POTENTIAL EFFECTS OF RELEASE OF HYDROCARBONS AND HEAVY METALS ON FISH HARVEST

Shorebases and shallow-water production facilities will release hydrocarbons and heavy metals at sufficient levels such that fish harvest will be reduced through tainting and heavy metal accumulations

HYPOTHESIS 13A



HYPOTHESIS 13B



LINKAGES FOR HYPOTHESIS 13A

1. and 3. Hydrocarbons in water and sediments will enter fish and prey organisms of harvested fish species.

2. Hydrocarbons can be passed through food chains.

4. Desirability of fish is decreased as a result of increases in body burden of hydrocarbons.

5. Decreased desirability will decrease fish harvest.

LINKAGES FOR HYPOTHESIS 13B

1. and 3. Heavy metals from water and sediments will enter fish and prey organisms of harvested fish species.

2. Heavy metals can be passed through food chains.

4. Human health and desirability of fish can be affected by increases in heavy metal concentrations.

5. Decreased desirability will decrease fish harvest.

BEMP PROJECT OVERVIEW NO. 13-1

TITLE:	Tainting of fishery resources
PRINCIPAL INVESTIGATORS:	W.G. Tidmarsh, R. Ernst, R. Ackman, T. Farquharson
AFFILIATION:	Martec Ltd., Canadian Institute of Fisheries Technology
FUNDING SOURCE:	ESRF
EXPECTED COMPLETION DATE:	Complete
RELEVANT BEMP HYPOTHESIS NUMBER(S):	13A, 20

BRIEF PROJECT DESCRIPTION

The major objectives of this study were:

1. to evaluate real or potential concerns associated with the tainting of fish resources due to oil spills or hydrocarbon development activities;

2. to assess the effectiveness of various methods and procedures used to detect tainting; and

3. to identify possible research and monitoring strategies for dealing with tainting.

A review of world literature on tainting revealed that tainting incidents have been, for the most part, poorly documented. Generally it has been found that tainting has been more prevalent in confined, shallow coastal embayments where sessile organisms or lipid-rich mobile species have been exposed to anthropogenic hydrocarbons. Experience in laboratory tests has yielded conflicting evidence on the risk and degree of possible tainting of fish and the actual taint-producing hydrocarbons present.

Because taint is a subjective sensory perception, it can only be evaluated by using sensory tools such as odour and taste tests. Chemical analysis can only assist in determining the possible types of hydrocarbons responsible for a taint. Standard methods for determining taint have not been adopted internationally.

Four types of sensory methods used by the food industry were assessed as tools for evaluating hydrocarbon taint. The triangle test, in which panelists are asked to detect the odd sample of three tested, was recommended. Tissue analysis of tainted products was recommended to support the findings of sensory evaluations by quantifying the hydrocarbons present compared to control samples.

The study made recommendations on the development of a series of standard methods for application in the event of an oil spill where fish tainting may be a concern. Recommendations were also made for basic research

relating to:

1. threshold levels of hydrocarbons causing tainting;

2. depuration rates in organisms after exposure;

3. potential tainting associated with the discharge of oil-base drilling muds, the discharge of production water, the application of dispersants and the presence of sunken oil; and

4. baseline levels of taint-producing anthropogenic hydrocarbons in selected species of commercial importance.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This study was initiated at least in part because of recommendations provided in relation to Hypothesis 13A, "Shorebases and shallow water production facilities will release hydrocarbons at sufficient levels such that fish harvest will be reduced through tainting". The project has provided information about the occurrence and detection of tainting as well as information about how tainting, or perceived tainting, has reduced fish harvests. The project also resulted in recommendations for research relevant to Hypothesis 20, "The discharge of cuttings contaminated with oil-base drilling muds during development of shallow-water production facilities will reduce populations of Arctic cisco, broad whitefish and lake whitefish and will also decrease the harvest of these species due to hydrocarbon accumulation (tainting)".

BEMP PROJECT OVERVIEW NO. 13-2

TITLE:	Measurements of contaminants in arctic marine fish
PRINCIPLE INVESTIGATORS:	D. Muir, L.Lockhart, R. Wegemann
AFFILIATION:	Fisheries and Oceans Canada, Freshwater Institute
FUNDING SOURCE:	INAC, DFO
EXPECTED COMPLETION DATE:	1986
RELEVANT BEMP HYPOTHESIS NUMBER(S):	13, 19

BRIEF PROJECT DESCRIPTION

The primary purpose of this study was to ascertain the level of potentially toxic contaminants in fish that might be used for human consumption. Marine fish were collected from seven locations across the arctic. Only two of these locations, Tuktoyaktuk harbour and Kugmallit Bay, were in the Beaufort Sea. The primary species of fish that were collected were Arctic cod, whitefish, sculpins, herring and flounder. Samples of liver, kidney, gonad and muscle tissue were analysed for concentrations of hydrocarbons, mixed function oxidases, heavy metals and organochlorines. With the exception of cadmium, concentrations of heavy metals were generally lower than previous reports for northern anadromous and freshwater species. High cadmium levels were found in sculpin and herring livers from Tuktoyaktuk.

Organochlorines (PCB's, chlordane, chlorobenzenes, hexachlorocyclohexanes (HCH) and toxaphene) were detected in all pooled fish muscle samples at low ng/g concentrations. Toxaphene and HCH were found at higher concentrations than the other compounds in herring from Tuktoyaktuk. Large differences in residue levels between species were found in fish from Tuktoyaktuk. Nevertheless, concentrations of all organochlorines were about 10 to 100 times lower than concentrations in fish from the east coast of Canada or the northwest Pacific.

Polyaromatic hydrocarbons (PAHs) (naphthalene, phenanthrene, methyl phenanthrene, flouranthene, pyrene and benz(a)pyrene) were detected in pooled fish muscle extracts. Highest concentrations of PAHs were found in fish muscle from Tuktoyaktuk and Resolute. PAH levels at Tuktoyaktuk and Kugmallit Bay were similar to previous reports for fish in this region but higher than reports for freshwater and marine fish in some southern Canadian studies. PAH results require further confirmation by mass spectrometry.

Mixed function oxidase enzyme activities in livers of fish from Tuktoyaktuk harbour were generally higher than in published reports on other species. However, no firm conclusions could be drawn because of lack of data on arctic species. Rapid freezing of livers dissected in the field resulted in somewhat higher mixed function oxidase activities than results from freezing of whole fish followed by dissection in the laboratory.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This study provides background information about levels of heavy metals and hydrocarbons in fish. These data are relevant to Link 1 of Hypotheses 13A and 13B. The study also provides information relevant to Hypothesis 19, "Dredging and deposition of dredge spoil will reduce the bearded seal population". Links 5 and 6 of this hypothesis suggest that contaminants released during dredging will be taken up by fish and benthos resulting in lower populations of these groups.

HYPOTHESIS NO. 14

NEARSHORE STRUCTURES WILL DISRUPT THE NEARSHORE BAND OF WARM BRACKISH WATER AND REDUCE THE BROAD WHITEFISH POPULATION

INTRODUCTION

Important habitats for broad whitefish in the Mackenzie Delta region include overwintering habitat in the main channels and nearshore areas adjacent to the delta, rearing habitat in the lakes and streams of the Tuktoyaktuk Peninsula, and migration and foraging habitat within a narrow band along the coast. Participants at the 1983-84 BEMP workshop concluded that there was insufficient evidence to allow acceptance or rejection of the hypothesis that nearshore structures would disrupt the nearshore band of brackish water and reduce the broad whitefish population.

During the 1985 BEMP workshop, discussion regarding the reasons for use of the nearshore area by broad whitefish resulted in the addition of links relating to changes in broad whitefish distribution as a result of changes in bottom slope. However, participants at this workshop agreed with the overall conclusion of the 1983-84 workshop. Participants in 1985 did note, however, that any effects of nearshore structures would be highly dependent on both the type of structure and the physical characteristics of the shoreline at the location of the structure.

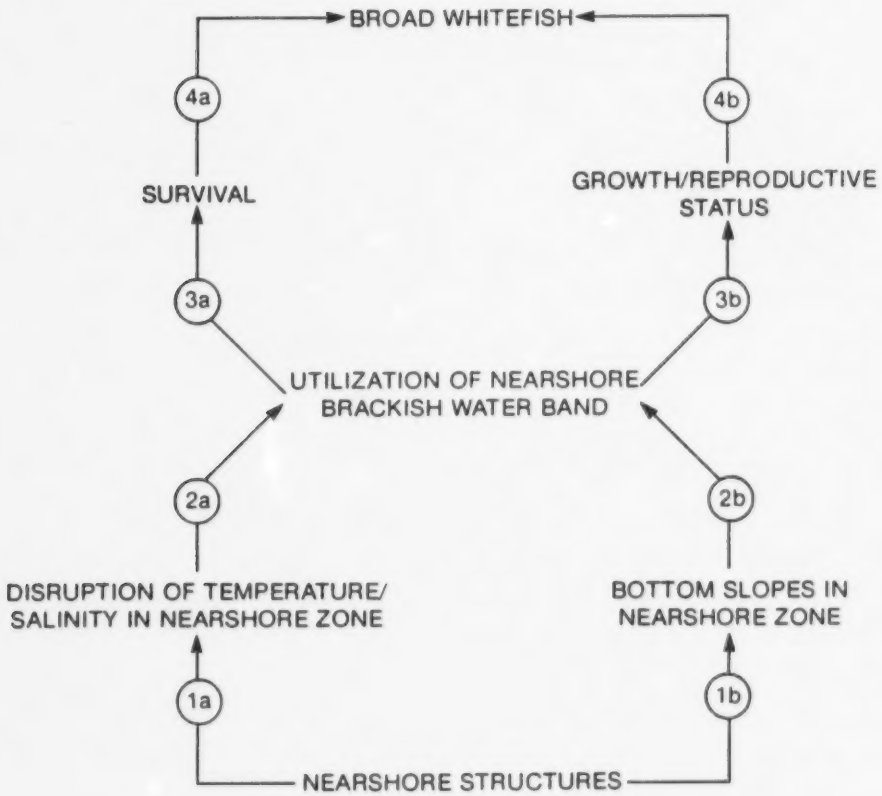
NEW INFORMATION

Several studies that are relevant to this hypothesis began or continued in 1985. Two studies addressed the migratory movements of broad whitefish in the Mackenzie Delta and along the Tuktoyaktuk Peninsula (Project Overviews 14-1 and 14-2). A third study (Project Overview 14-3) continued the examination of broad whitefish to determine whether separate stocks exist within the Mackenzie River drainage and a fourth (Project Overview 14-4) examined salinity tolerances of young whitefish of several species including broad whitefish. Finally, the study of the ARCO causeway at Prudhoe Bay that was discussed in 1985 is now complete (Project Overview 15-1). This study provides the only direct evidence for effects of nearshore structures on fish distribution.

FIGURE 14-1

POTENTIAL EFFECTS OF NEARSHORE STRUCTURES ON THE BROAD WHITEFISH POPULATIONS

Nearshore structures will disrupt the nearshore band of warm brackish water and reduce the broad whitefish population



LINKAGES

1a. Shoreline modifications will change temperature and salinity characteristics of the brackish water band along the Tuktoyaktuk Peninsula.

1b. Nearshore structures will change the slope of the sea bottom within the brackish water band along the Tuktoyaktuk Peninsula.

2a. Disruption of the brackish water band will result in decreased utilization of the nearshore zone by broad whitefish.

2b. Changes in nearshore sea bottom slope will alter utilization of nearshore waters by broad whitefish.

3a. The reduced time spent in the nearshore brackish zone will cause an increase in mortality of broad whitefish.

3b. Disruption of nearshore habitat will cause a decrease in feeding time and consequently a reduction in growth and fecundity.

4a. Increase in mortality of broad whitefish would lead to a decrease in the number of spawners, and subsequent reduction in the number of harvestable fish.

4b. Reduction in fecundity and reduced viability of eggs and young would result in fewer available fish for the harvest.

BEMP PROJECT OVERVIEW NO. 14-1

TITLE:	Fish migration along the Tuktoyaktuk Peninsula
PRINCIPAL INVESTIGATOR:	K. Chang-Kue
AFFILIATION:	Fisheries and Oceans Canada, Freshwater Institute
FUNDING SOURCE:	DFO, NOGAP
COMPLETION DATE:	1987
RELEVANT BEMP HYPOTHESIS NUMBER(S):	14

BRIEF PROJECT DESCRIPTION

This study is a continuation of 1985 BEMP Project Overview No. 26. The study is investigating movements of broad whitefish in the Tuktoyaktuk Peninsula and Mackenzie estuary areas. Earlier studies had shown that juvenile broad whitefish summer in drainages on the Tuktoyaktuk Peninsula and winter either in the same drainages or in shallow coastal bays. Tagged fish were recovered years later as spawning migrants in the Mackenzie Delta.

The present study is based on the use of radio tags and is designed to provide detailed information on the fall migration of adult broad whitefish to their spawning areas as well as identifying the actual spawning sites. Information is also being obtained on the over-wintering areas of post-spawning fish and juvenile fish from the Tuktoyaktuk Peninsula drainages.

In 1985, 36 broad whitefish in the 9-12 yr age class were radio-tagged on the Tuktoyaktuk Peninsula in July. All of these fish moved westward along the Peninsula and all followed the coastline closely. Twenty-three of the tagged fish were harvested in Tuktoyaktuk Harbour, substantially reducing the sample size. However, five of the remaining fish displayed spawning movements and behaviour in the Mackenzie Delta. This was unexpected since it had been believed that mature broad whitefish remained in the delta through the summer.

In 1986 broad whitefish will be tagged in a drainage that lies between Tuktoyaktuk and the Mackenzie Delta in order to assess whether fish migrating to wintering areas move solely toward the delta or if some fish also move eastward.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This study is most relevant to Hypothesis 14 which states that "Nearshore structures will disrupt the nearshore band of warm brackish water along the Tuktoyaktuk Peninsula and reduce the broad whitefish population". The underlying assumption of this hypothesis is that broad whitefish use the warm brackish water found along the Tuktoyaktuk Peninsula as a migratory route between spawning or overwintering areas in the Mackenzie River or estuary and rearing areas in freshwater lakes on the Peninsula. Interruption of this route by, for example, the diversion of coastal waters to offshore

areas by long causeways, could have population-wide effects on the broad whitefish that inhabit the region either through decreased survival (Link 4a) or decreased growth and reproductive potential (Link 4b). This study addresses major data deficiencies regarding the seasonal use of nearshore waters of the Beaufort Sea by broad whitefish.

BEMP PROJECT OVERVIEW NO. 14-2

TITLE:	Whitefish migration in the Mackenzie River and estuary
PRINCIPAL INVESTIGATOR:	K. Chang-Kue
AFFILIATION:	Fisheries and Oceans Canada, Freshwater Institute
FUNDING SOURCE:	DFO, NOGAP
EXPECTED COMPLETION DATE:	Complete
RELEVANT BEMP HYPOTHESIS NUMBER(S):	14, 16

BRIEF PROJECT DESCRIPTION

This study was a continuation of an investigation involving the radio tracking of broad whitefish and to a lesser extent lake whitefish. Specimens were captured in the lower Mackenzie Delta at Horseshoe Bend in Middle Channel during the fall, released and then their locations periodically monitored through the use of fixed-wing aircraft. Most of the information that has resulted from this study relates to location of overwintering in areas in or near the Mackenzie River estuary and spawning areas in regions upstream from the delta.

Most data obtained during the course of this investigation have been for broad whitefish, since their large size allows the use of radio tags with less stress than is possible with the smaller species. The data indicate that mature spawners of the year begin moving into delta waters during mid-September. Broad whitefish then hold or move slowly upstream until late October, when they begin a concentrated upstream movement to spawning areas. Spawning is likely completed by mid-November. Shortly after spawning, broad whitefish move downstream and are in the Mackenzie River estuary by early December, where they remain with little movement until March. Results suggest that overwintering occurs near Whitefish Station and in Shallow Bay and possibly Tuktoyaktuk Harbour.

Mature lake whitefish have movement patterns similar to those of broad whitefish, but these movements occur about two weeks earlier.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

Whitefish populations in the Beaufort region are anadromous, and it is presently assumed that virtually all individuals found in the BEMP study area originate in the Mackenzie River drainage. Therefore, while this whitefish migration study was conducted largely in fresh water, some information from the investigation will likely be relevant to other research or monitoring designed specifically to address BEMP hypotheses. For example, data on the timing of spawning migration will be important in determining (1) when mature fish leave the Beaufort Sea or Mackenzie River estuary region, and thus could not be affected by industrial activities, and (2) probable periods of migration through coastal waters of the Beaufort Sea. Identification of overwintering areas in estuarine waters of the Beaufort region is of obvious interest.

BEMP PROJECT OVERVIEW NO. 14-3

TITLE:	Whitefish stock description
PRINCIPAL INVESTIGATOR:	J. Reist
AFFILIATION:	Fisheries and Oceans Canada, Freshwater Institute
FUNDING SOURCE:	DFO, NOGAP
EXPECTED COMPLETION DATE:	1988
RELEVANT BEMP HYPOTHESIS NUMBER(S):	14, 16, 17

BRIEF PROJECT DESCRIPTION

The purpose of this study is to determine the discreteness and number of broad whitefish stocks in the Mackenzie River drainage. Collections were made from spawning aggregations in the major tributaries of the lower Mackenzie. Morphometric data, consisting of measurements and counts from the external body, and electrophoretic data, consisting of visualization of specific enzyme phenotypes, were obtained. Both these types of data indicate structuring of the Mackenzie fish into separate stocks. However, further work is required before discrete stocks can be definitively identified.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This study is of interest to all of the hypotheses concerning broad whitefish because it may provide data that will aid in assessment of the possible magnitude or severity of the effects of hydrocarbon development on this species. If separate populations of broad whitefish exist in the region, individual populations may be more susceptible to some development activities, particularly if such populations remain as relatively discrete units while in the Beaufort Sea.

BEMP PROJECT OVERVIEW NO. 14-4

TITLE:	Salinity tolerance of whitefish
PRINCIPAL INVESTIGATOR:	B. deMarch
AFFILIATION:	Fisheries and Oceans Canada, Freshwater Institute
FUNDING SOURCE:	DFO, NOGAP
EXPECTED COMPLETION DATE:	1988
RELEVANT BEMP HYPOTHESIS NUMBER(S):	14

BRIEF PROJECT DESCRIPTION

The objective of this study is to determine the extent to which juvenile whitefish (including broad whitefish, lake whitefish and lake cisco) can tolerate saline conditions, in order to help explain and predict whitefish migration corridors. Juvenile fish were exposed to environmentally realistic salinities during laboratory experiments. All species exhibited considerable tolerance at 15°C. The experiments will be repeated at lower temperatures in order to test whether fish are less tolerant of high salinities when stressed by cold.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This study is relevant to Hypothesis 14, "Nearshore structures will disrupt the nearshore band of warm brackish water and reduce the broad whitefish population". Although broad whitefish apparently prefer brackish water, this study indicates that they can tolerate more saline water. This study does not, however, address the recommendation of the 1983-84 BEMP Final Report that laboratory studies of the temperature and salinity <u>preferences</u> of broad whitefish be conducted.

HYPOTHESIS NO. 15

NEARSHORE STRUCTURES WILL DISRUPT THE NEARSHORE BAND OF WARM BRACKISH WATER AND WILL REDUCE THE ALASKAN POPULATION OF ARCTIC CISCO

INTRODUCTION

The Mackenzie River is believed to be the source of the Arctic cisco that occur along the north coast of Alaska. Thus, nearshore structures along the Yukon coast could result in disruption of migration patterns through changes in the salinity and temperature characteristics of the nearshore zone. Participants at both the 1983-84 and 1985 BEMP workshops concluded that the hypothesis could not be proven or disproven based on available evidence.

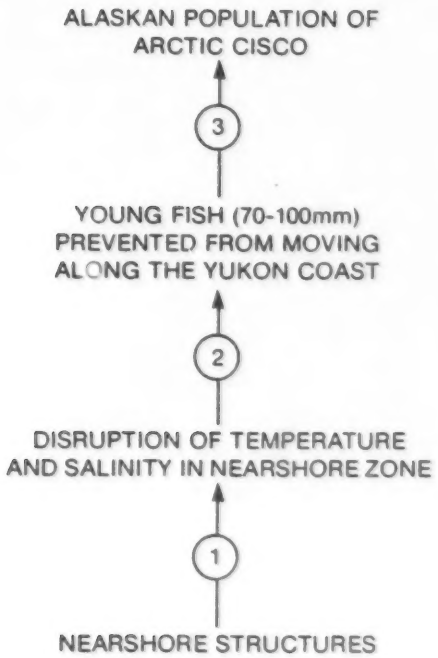
NEW INFORMATION

Completion of the study of the effects of the ARCO causeway at Prudhoe Bay (Project Overview 15-1) provides evidence that the causeway did result in altered distribution at least small Arctic cisco. Two other studies conducted along the Yukon coast also provide information relevant to this hypothesis. Project Overview 15-2 describes ongoing work relevant to determining whether 'Alaskan Arctic cisco' do indeed originate from the Mackenzie River. The study described in Project Overview 15-3 will provide information about the amount of natural variability in temperature and salinity regimes along the Yukon coast.

FIGURE 15-1

POTENTIAL EFFECTS OF NEARSHORE STRUCTURES ON THE ALASKAN POPULATION OF ARCTIC CISCO

Nearshore structures will disrupt the nearshore band of warm brackish water and reduce the Alaskan population of Arctic cisco


ALASKAN POPULATION OF ARCTIC CISCO
3
YOUNG FISH (70-100mm) PREVENTED FROM MOVING ALONG THE YUKON COAST
2
DISRUPTION OF TEMPERATURE AND SALINITY IN NEARSHORE ZONE
1
NEARSHORE STRUCTURES

LINKAGES

1. Shoreline modification will change temperature and salinity patterns
the brackish water band along the Yukon Coast during summer.

2. Disruption of the brackish water band will result in decreased moveme
of young Arctic cisco from the Mackenzie Delta to the Alaskan Beaufo
Sea coast.

3. Decreased movement of Arctic cisco will cause directly proportion
decreases in the Alaskan population of Arctic cisco.

BEMP PROJECT OVERVIEW NO. 15-1

TITLE:	Fish movement and habitat in relation to the ARCO causeway in Prudhoe Bay, Alaska
PRINCIPAL INVESTIGATORS:	L.L. Moulton, B.J. Gallaway, M.H. Fawcett, W.B. Griffiths, K.R Critchlow, R.G. Fechhelm, D.R Schmidt, J.S. Baker
AFFILIATION:	Entrix, Inc., Anchorage, AK; LGL Ecological Research Associates, Bryan, TX; Woodward-Clyde Consultants, Anchorage, AK
FUNDING SOURCE:	Prudhoe Bay Unit (ARCO, MMS, Army Corps of Engineers)
EXPECTED COMPLETION DATE:	Complete
RELEVANT BEMP HYPOTHESIS NUMBER(S):	14, 15

BRIEF PROJECT DESCRIPTION

This study was conducted from 1 July to 20 September 1984 in coastal regions of the Alaskan Beaufort Sea between Gwydyr Bay and the Sagavanirktok River delta. The overall objective of the study was to determine the effects of the Prudhoe Bay causeway on fish, their physical habitat and their prey. A total of 27 stations were sampled during the course of the field studies, usually on a daily basis. Physical variables measured at each station included temperature, salinity, wave height and turbidity. Fish prey organisms (drop net samples) and fish (fyke net samples) were also collected at each site. A total of about 55,000 fish, mostly broad whitefish, Arctic cisco, least cisco and Arctic char, were marked by either freeze branding or Floy tags to obtain data on individual fish movements through mark-recapture techniques.

The majority of the char, broad whitefish and small Arctic cisco in the study area apparently dispersed from wintering areas in the Sagavanirktok River or delta while least cisco and large Arctic cisco moved into the area after overwintering in the Colville River delta. Many of the large broad whitefish and juvenile Arctic cisco caught at stations west of the West Dock causeway likely came from overwintering areas in the Colville delta. Results for Arctic cisco are consistent with the hypothesis that most, if not all, of the Arctic cisco in the study area originate from a spawning stock in the Mackenzie River.

In 1984 small Arctic cisco, broad whitefish and char tended to remain within Prudhoe Bay with little western dispersal into the Gwydyr Bay lagoon system. Small least cisco tended to remain within the Gwydyr Bay lagoon system. These patterns appeared to be caused, at least in part, by the presence of West Dock causeway, which apparently hindered east-west movement of small anadromous fish into and out of the lagoon system. In contrast, large Arctic cisco, least cisco and char moved widely throughout the study area, while large broad whitefish tended to remain near the river deltas.

Arctic cisco in the Prudhoe Bay portion of the study were primarily 2-yr-old and 5-yr-old fish. Arctic cisco in the Gwydyr Bay lagoon system were primarily 5 yr or older. Least cisco throughout the study area were primarily age 5 to age 12 and older.

Growth rates for least cisco, broad whitefish and char were similar to previously reported rates and showed no differences among areas. In contrast, Artcic cisco in the Sagavanirktok region showed a lower growth rate than in past studies, and a lower rate than the same cohort in the Colville region.

Total prey biomass within Prudhoe Bay was lower than biomass in the Gwydyr Bay lagoon system in early and mid-summer. During early and mid-summer, the period of greatest fish abundance, there was little dietary overlap among the fish species. Later in the summer there was significant overlap among the anadromous fish species. Comparison of fish diets with available food showed few consistent patterns of selectivity for particular prey species. Arctic cisco were the only fish showing a relationship between biomass of food available and biomass of stomach contents. Multiple regression of fish abundance with habitat parameters showed that temperature and salinity accounted for the greatest amount of observed variation. The addition of prey as a habitat variable did not substantially increase the amount of variation explained.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This study is of obvious and direct relevance to Hypothesis 14, "Nearshore structures will disrupt the nearshore band of warm brackish water and reduce the broad whitefish population" and Hypothesis 15, "Nearshore structures will disrupt the nearshore band of warmer brackish water and will reduce the Alaskan population of Arctic cisco". The present study provides directly relevant information for both of the species of fish involved in these hypotheses. In the case of Arctic cisco (Hypothesis 15), the same population could be affected by both the Prudhoe Bay causeway and all nearshore structures built between the Mackenzie Delta and the westward limit of Arctic cisco distribution in the Alaskan Beaufort Sea.

BEMP PROJECT OVERVIEW NO. 15-2

TITLE:	North Slope (Yukon coast) impact assessment
PRINCIPAL INVESTIGATOR:	W. Bond
AFFILIATION:	Fisheries and Oceans Canada, Freshwater Institute
FUNDING SOURCE:	DFO, NOGAP
EXPECTED COMPLETION DATE:	1988
RELEVANT BEMP HYPOTHESIS NUMBER(S):	15, also of general interest

BRIEF PROJECT DESCRIPTION

The primary objectives of this study are to:

1. obtain baseline biological descriptions of the marine and anadromous fishes using nearshore habitats along the Yukon coast (species composition and distributions, age and growth, sex and maturity, food habits);

2. describe the alongshore migratory patterns of anadromous fish (both spatially and seasonally);

3. identify specific areas that may be of importance to marine and anadromous fishes as feeding, spawning, nursery or overwintering habitat; and

4. characterize inshore habitats (to the 5-m isobath) in terms of temperature and salinity, and relate these variables to fish distribution and movement patterns.

Over the course of the study gillnets trapnets and seines will be used to sample marine and anadromous fish populations between Kay Point and Calton Point. Most sampling will occur in the open water season, although limited winter field studies are also anticipated. The extent of anadromous fish movements will be evaluated through the use of convential (Floy) tags.

The area studied in 1985 was that enclosed by the 5-m isobath between Kay Pt. and Stokes Pt. Both the Babbage and Spring rivers enter the Beaufort Sea within this area. Fish were sampled on a weekly basis from 29 June to 21 August at 24 stations. Water temperature, salinity and conductivity were determined with each fish collection. In both inshore and offshore areas arctic cisco was the species most frequently captured.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This study is particularly relevant to Hypothesis 15 which states that 'Nearshore structures will disrupt the nearshore band of warmer brackish water and will reduce the Alaskan population of Arctic cisco'. The study will define use of the nearshore zone as a migration corridor for Arctic cisco and other species. The results of this 5-year program could verify or disprove

the underlying assumption of Hypothesis 15. The assumption is that 'Alaskan Arctic cisco' spawn in the Mackenzie River and then juveniles migrate along the Yukon coast to spend a number of years in Alaskan waters before mature or nearly mature fish return to the Mackenzie River to spawn.

In addition, this study is expected to provide basic descriptive information for other fish species which occur along the Yukon coast. These data will provide the basis for evaluation of the need for future monitoring programs related to hydrocarbon development activities in this part of the southeastern Beaufort Sea.

BEMP PROJECT OVERVIEW NO. 15-3

TITLE:	King Point coastal zone sediment transport study
PRINCIPAL INVESTIGATORS:	R. Gillie; P. Morgan
AFFILIATION:	Dobrocky Seatech Ltd., Halifax, N.S.; Atlantic Geoscience Centre, Dartmouth, N.S.
FUNDING SOURCE:	Atlantic Geoscience Centre, Bedford Institute of Oceanography
EXPECTED COMPLETION DATE:	March 1986
RELEVANT BEMP HYPOTHESIS NUMBER(S):	10, 13, 15

BRIEF PROJECT DESCRIPTION

The primary objective of this project was to provide an improved understanding of sediment transport processes along the Yukon coastline. Data were collected from 28 August to 14 September 1985 in the vicinity of King Point, the proposed site of an onshore terminal to support the offshore oil and gas development in the Beaufort Sea. During the field program, current meter data were collected at four sites in water depths ranging from 1-20 m. Two of the current meters also provided information on directional wave properties, while the other two were equipped with temperature sensors. Beach profile data along with other bathymetric measurements were also obtained, as were measurements of suspended sediment concentrations and wind data.

The data collected are presently being analysed. Preliminary results suggest that water properties in the nearshore zone are subject to very large changes over periods of a few days or less.

Once the analysis of the 1985 data is completed, the sediment transport results will be compared with the sediment transport computed by a numerical model, previously developed for use in the Beaufort Sea.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

The results of the study are expected to be relevant to Hypothesis No. 15, which concerns the possible effect of nearshore structures in reducing the movement of Arctic cisco along the Yukon coastline. This study will provide additional data on water property (temperature, current and suspended sediment) variations within the Yukon nearshore zone. Given the present paucity of such data, the results should provide an improved description of the natural levels of variability of water properties over time, and the role of wind forcing in changes in water properties of the nearshore zone. The results are also relevant to Hypotheses 10 and 13, both of which deal with environmental effects associated with chronic oil spills and other contaminants released from shorebases and shallow water production facilities. The results of this program will provide information concerning the possible fate and dispersal of released oil and other contaminants along the Beaufort Sea coast.

HYPOTHESIS NO. 16

THE CONSTRUCTION OF SHOREBASES AND DEVELOPMENT OF SHALLOW-WATER PRODUCTION FIELDS WILL RESULT IN A DECREASE IN THE POPULATIONS OF ARCTIC CISCO AND BROAD WHITEFISH

INTRODUCTION

When BEMP was initiated the development scenario for the Beaufort Sea did not envision production facilities in water depths less than 5 m. The participants at the 1983-84 BEMP workshop concluded that discharges from facilities at depths greater than 5 m were unlikely to affect Arctic cisco or broad whitefish. The hypothesis was re-evaluated in 1985 because of the possibility that production facilities for the ADCO field would be located in water less than 3 m deep. Because of the very small volume of effluent expected from development of this field, the participants again concluded that effects on populations of Arctic cisco and broad whitefish were unlikely.

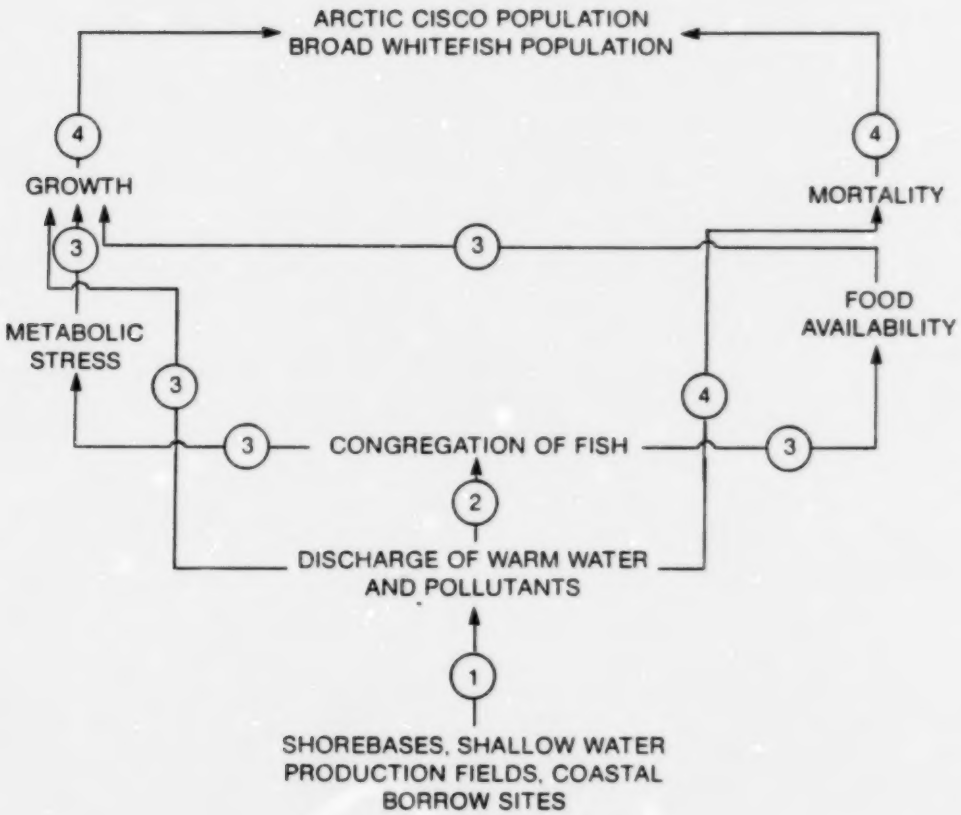
NEW INFORMATION

Information about broad whitefish migration routes in the Mackenzie delta area (Project Overview 14-2) is relevant to this hypothesis since only fish that are exposed to effluents could be affected by them. Information from the work described in Project Overview 16-1 will contribute to an understanding of the importance of the delta area for feeding. Identification of discrete stocks of broad whitefish (Project Overview 14-3) would be relevant to this hypothesis since individual stocks may have different migration routes and be differentially exposed to effluents.

FIGURE 16-1

POTENTIAL EFFECTS OF DISCHARGES FROM PRODUCTION FIELDS AND OTHER FACILITIES ON ARCTIC CISCO AND BROAD WHITEFISH POPULATIONS

The construction of shorebases and development of shallow-water production fields will result in a decrease in the populations of Arctic cisco and broad whitefish



LINKAGES

1. Warm water effluents and production water will be discharged into the freshwater area of the outer Mackenzie Delta.

2. Fish will be attracted to thermal plumes.

3. Contaminants in produced water in areas where fish are congregated will result in increased stress, reduced food availability and decreased fish growth.

4. Direct mortality due to effluents and decreased growth will reduce Arctic cisco and broad whitefish populations.

BEMP PROJECT OVERVIEW NO. 16-1

TITLE:	Physical, chemical and biological characteristics of broad whitefish habitats, Mackenzie Delta area.
PRINCIPAL INVESTIGATOR:	E. Fee
AFFILIATION:	Fisheries and Oceans Canada, Freshwater Institute
FUNDING SOURCE:	NOGAP
EXPECTED COMPLETION DATE:	1987
RELEVANT BEMP HYPOTHESIS NUMBER(S):	16

BRIEF PROJECT DESCRIPTION

The objective of this study is to define the environmental and biological properties of lakes that are important to broad whitefish populations. Primary production in the lakes on the Tuktoyaktuk Peninsula provides the main food base for juvenile broad whitefish. Macrophyte production in lakes on both the peninsula and the Mackenzie Delta provides the food base for adult broad whitefish. Lakes in the two areas are subject to quite different forces. On the delta, lakes are regularly flushed by the spring flood and water levels drop by 2 to 3 m during the summer. Turbidities in delta lakes are high, thus inhibiting plant growth. Lakes on the Tuktoyaktuk Peninsula are much more stable with low turbidity. During this study the quantity of fish food available in these two areas will be analysed and the isotopic composition of fish and their foods will be analysed to determine the important food resources and where fish feed.

In 1985, samples were taken from four lakes and two channels on the Mackenzie delta, from the Kukjuktuk estuary and from five lakes in the Kukjuktuk drainage on the Tuktoyaktuk Peninsula. Physical variables measured included incident solar radiation (measured continuously at Inuvik), turbidity, upwelling and downwelling irradiances, surface temperature (in channels), and temperature profiles (in lakes). Chemical analyses are being made of 33 rainwater samples and of 94 vertically integrated water samples from lakes and channels. In situ determinations of conductivity, pH, and dissolved oxygen were made at 118 stations. Sediment cores were taken from all sites to determine sedimentation rates and stable isotopic composition. Water samples were also taken for determining stable isotopic composition. Rates of primary production were measured for both delta and peninsula lakes and samples of phytoplankton, macrophytes, benthos and zooplankton were collected for identification and enumeration. Macrophytes, benthos and fish were collected from both locations for stable isotope composition analysis.

Preliminary findings of this study support the hypothesis that whitefish migrate from delta lakes to lakes on the Tuktoyaktuk Peninsula because conditions for feeding and growth are better there.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This study is of most relevance to Hypothesis 16 which states that "The construction of shorebases and development of shallow-water production fields will result in a decrease in the populations of Arctic cisco and broad whitefish" through attraction of fish to warm water discharge and subsequent metabolic stress and competition for food. This study will provide information on feeding areas of broad whitefish and the importance of the Mackenzie Delta as a feeding area.

HYPOTHESIS NO. 17

WATER INTAKES WILL REDUCE POPULATIONS OF BROAD WHITEFISH AND ARCTIC CISCO

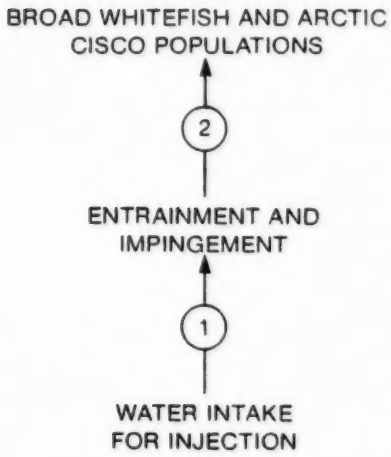
INTRODUCTION

Intake of water for reservoir injection in the Canadian Beaufort Sea is expected to be very small compared to intake for this purpose in Alaska. Participants at both the 1983-84 and 1985 BEMP workshops reviewed the available evidence for effects on Arctic cisco and broad whitefish in Alaska and concluded that this hypothesis was very unlikely to be true in the Canadian Beaufort Sea. Participants recommended that results of Alaskan studies should be reviewed as they become available and that the hypothesis should be re-evaluated if the Alaskan studies suggest effects may be greater than initially thought.

FIGURE 17-1

POTENTIAL EFFECTS OF WATER INTAKES ON BROAD WHITEFISH AND ARCTIC CISCO POPULATIONS

Water intakes will reduce populations of broad whitefish and Arctic cisco.



LINKAGES

1. The intake of water for reservoir injection will cause entrainment and impingement of juvenile broad whitefish and Arctic cisco.

2. The mortality associated with entrainment and impingement will reduce broad whitefish and Arctic cisco populations.

HYPOTHESIS NO. 19

DREDGING AND DEPOSITION OF DREDGE SPOIL WILL REDUCE THE BEARDED SEAL POPULATION

INTRODUCTION

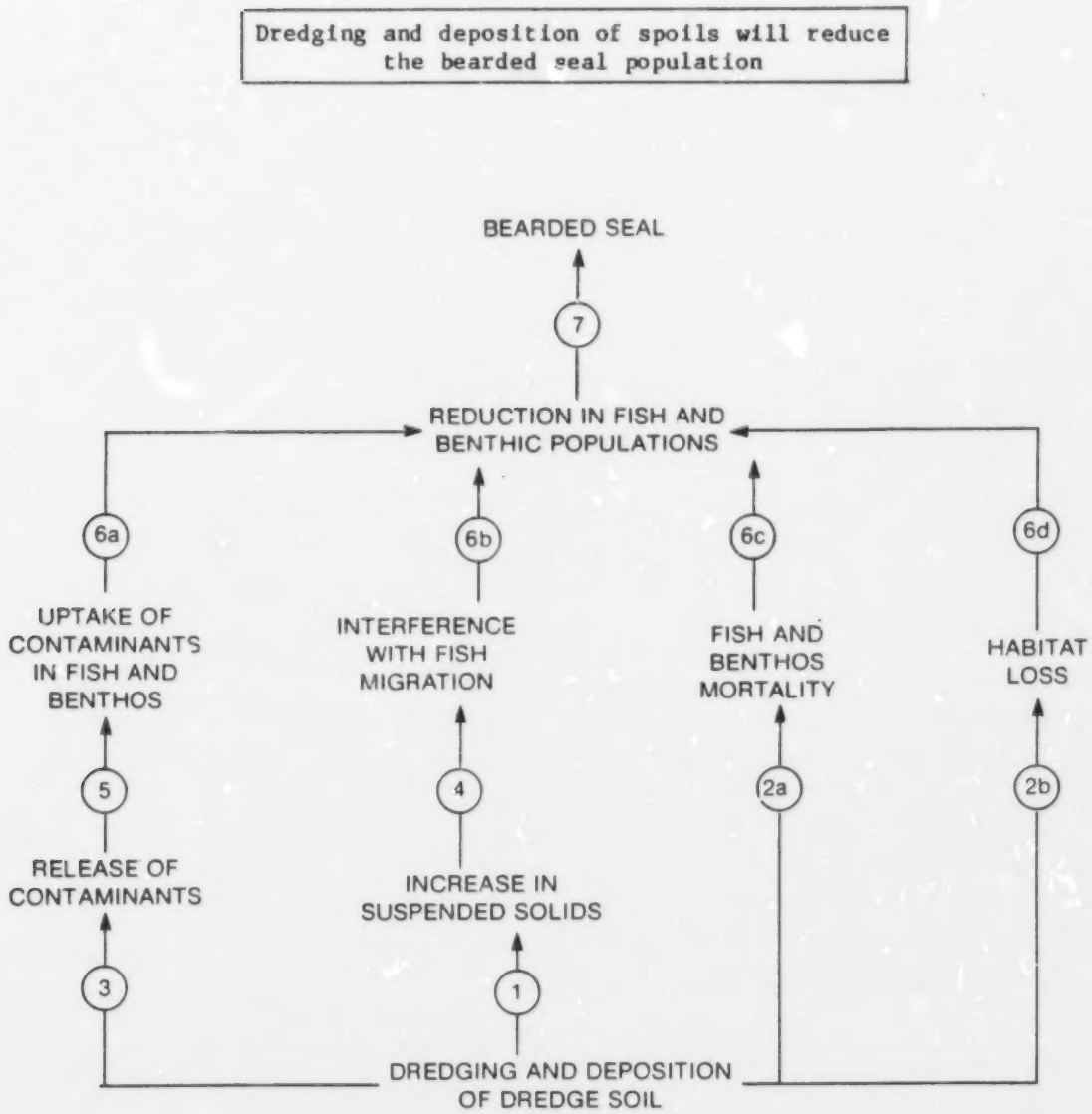
This hypothesis was not evaluated at the 1983-84 workshop. Selected participants from that workshop reviewed the evidence and linkages for the hypothesis and concluded that it was unlikely. A working group at the 1985 BEMP workshop again reviewed the evidence for this hypothesis and also concluded that it was unlikely.

NEW INFORMATION

The only study conducted in 1985 that is directly relevant to this hypothesis concerns the effects of dredging on benthic invertebrates in Tuktoyaktuk Harbour (Project Overview 19-1). Two other projects may be indirectly relevant. Studies of Mackenzie shelf fisheries habitat relationships (Project Overview 6-2) may provide insight into trophic relationships that would be relevant to this hypothesis. The study of hydrocarbon and heavy metal concentrations in fish (Project Overview 13-2) will provide background information on concentrations of these contaminants in fish.

FIGURE 19-1

POTENTIAL EFFECTS OF DREDGING AND DEPOSITION OF SPOILS ON THE BEARDED SEAL POPULATION



LINKAGES

1. Dredging and deposition of dredge spoils will increase concentrations of suspended solids in the water column.

2. Removal of seafloor material and its deposition in other areas will result in mortality of benthic invertebrates and fish and habitat loss.

3. Dredging will release contaminants from the sediments.

4. Increased suspended solids will interfere with fish migration.

5. Contaminants released during dredging will be taken up by fish and benthos.

6. Habitat loss, mortality, interference with migratory routes and uptake of contaminants will reduce fish and benthic invertebrate populations.

7. Reduced populations of prey (fish and benthos) will reduce the number of bearded seals.

BEMP PROJECT OVERVIEW NO. 19-1

TITLE:	Nearshore benthic monitoring
PRINCIPAL INVESTIGATOR:	M. Lawrence
AFFILIATION:	Fisheries and Oceans Canada, Freshwater Institute
FUNDING SOURCE:	DFO, NOGAP
EXPECTED COMPLETION DATE:	1990
RELEVANT BEMP HYPOTHESIS NUMBER(S):	19 and of general interest

BRIEF PROJECT DESCRIPTION

The objectives of this study are to determine annual and seasonal variability in the standing stock of the macrofaunal and meiofaunal populations of benthos in various embayments along the Beaufort Sea coastline. The present study sites are Tuktoyaktuk Harbour and Mason Bay.

Van Veen grabs and small-diameter corers are being used to sample macrofauna and meiofauna, respectively. A random-stratified sampling strategy is being employed at locations with a similar mud-type substrate and minimum bottom slope. Sampling stations are located at depths of 3 to 5 m, 10 to 12 m and 15 to 20 m. The species, numbers, weight and size of predominant species of macrobenthos are being determined as are species and numbers of meiofauna. Sedimentation rates, salinity, temperature, sediment texture and the organic content of substrates are being measured to determine factors influencing species abundance and biomass. In addition, carbon, nitrogen and phosphorus determinations will be conducted on collected sediments, while water column measurements will include determinations of chlorophyll, total particulate concentrations and analysis of particulate and dissolved carbon, nitorogen and phosphorus.

Sampling is being conducted in February/March and August of each year at the 10 to 12 m depth stratum. Sample and data analysis are ongoing but some preliminary data are expected to be published in January 1986 in the Fisheries and Oceans Data Report series.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This study is of direct relevance to Hypothesis 19 which states that 'Dredging and deposition of spoils will reduce the bearded seal population'. More specifically, the study will examine the effects of dredging on invertebrates in Tuktoyaktuk Harbour and undisturbed populations in other bays. This information will be useful in determining the validity of Link 7 of Hypothesis 19, which assumes that dredging will reduce bearded seal populations as a result of decreased abundance of one of their primary sources of food (i.e. benthic invertebrates).

HYPOTHESIS NO. 20

THE DISCHARGE OF CUTTINGS CONTAMINATED WITH OIL-BASE DRILLING MUDS DURING HYDROCARBON EXPLORATION AND PRODUCTION WILL REDUCE POPULATIONS OF FISH, BIRDS AND MARINE MAMMALS, AND WILL ALSO DECREASE THE HARVEST OF THESE RESOURCES DUE TO HYDROCARBON ACCUMULATION OF TISSUES

INTRODUCTION

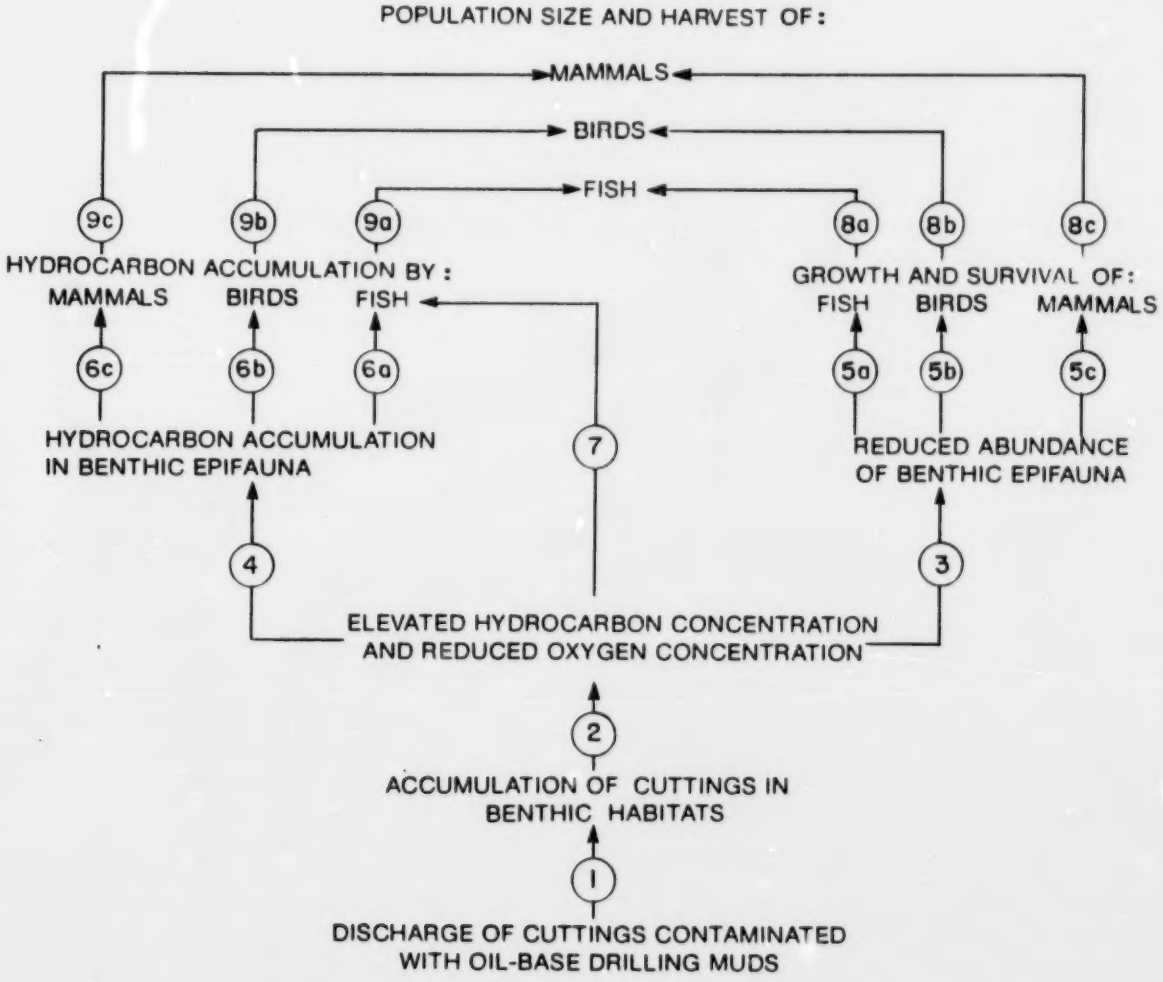
This hypothesis was restructured in the current study and its present form is shown in Figure 20-1. This change illustrates a broader range of potential effects of the use of oil-base drilling muds in the Beaufort Sea than was expressed in the 1984-85 BEMP workshop. Included in the present hypothesis are potential effects on harvesting as well as potential effects on various species of fish, birds and marine mammals. As was previously explained the planned detailed examination of the validity of this hypothesis was not possible to perform in the 1985-1986 BEMP program. Future detailed examination is obviously warranted.

The following material describes investigations of 1985-1986 studies as they relate to Hypothesis 20. Most studies are concerned with chemistry of hydrocarbons (Links 1 and 2) or biological effects (Links 3, 4, 5 and 6).

FIGURE 20-1

EFFECTS OF CUTTINGS CONTAMINATED WITH OIL-BASE DRILLING MUDS ON THE POPULATIONS AND HARVEST OF FISH, BIRDS AND MARINE MAMMALS

The discharge of cuttings contaminated with oil-base drilling muds during hydrocarbon exploration and production will reduce populations of fish, birds and marine mammals, and will also decrease the harvest of these resources due to hydrocarbon accumulation in tissues.



LINKAGES

1. Cuttings contaminated with oil-base drilling muds and discharged during exploration and development drilling will rapidly settle to the seafloor, and resist subsequent widespread dispersion due to the cohesiveness of mud-cuttings mixtures.

2. In areas of cuttings accumulation, elevated hydrocarbon concentrations and reduced oxygen levels will occur during the slow degradation of oil-base muds.

3. The abundance of benthic fauna will be reduced in areas of mud-cuttings accumulation due to smothering, oxygen depletion and toxicity of petroleum hydrocarbons in drilling muds or the products resulting from their degradation.

4. Benthic fauna in habitats containing mud-cuttings mixtures will accumulate petroleum hydrocarbons.

5a. Decreased abundance of benthic fauna will affect the growth and survival of marine and anadromous fish.

5b. Decreased abundance of benthic fauna will affect the growth and survival of birds that feed on benthic prey organisms.

5c. Decreased abundance of benthic fauna will affect the growth and survival of marine mammals that feed on benthic prey organisms.

6a. Marine and anadromous fish will accumulate petroleum hydrocarbons from ingestion of contaminated prey.

6b. Birds will accumulate petroleum hydrocarbons from ingestion of contaminated prey.

6c. Marine mammals will accumulate petroleum hydrocarbons from ingestion of contaminated prey.

7. Marine and anadromous fish remaining in areas containing oil-contaminated cuttings will directly accumulate petroleum hydrocarbons.

8a. The size of marine and anadromous fish populations will be reduced due to local effects of reduced prey availability on growth and survival.

8c. The size of marine mammal populations will be reduced due to local effects of reduced prey availability on growth and survival.

9a. The harvest of fish will be reduced due to the presence of petroleum hydrocarbons in tissues or the perception that fish are of lower quality.

9b. The harvest of birds will be reduced due to the presence of petroleum hydrocarbons in tissues or the perception that birds are of lower quality.

9c. The harvest of marine mammals will be reduced due to the presence of petroleum hydrocarbons in tissues or the perception that marine mammals are of lower quality.

BEMP PROJECT OVERVIEW NO. 20-1

TITLE:	Oil-based drilling muds; off structure monitoring West Venture C-62 and South Des Barres O-76 Sable Island
PRINCIPAL INVESTIGATORS:	M.B. Yunker and R.W. Drinnan
AFFILIATION:	Dobrocky Seatech Ltd.
FUNDING SOURCE:	ESRF
EXPECTED COMPLETION DATE:	1985
RELEVANT BEMP HYPOTHESIS NUMBER(S):	20

BRIEF PROJECT DESCRIPTION

The purpose of this study was to determine the areal distribution and dispersal of base oil from drilling mud contaminated cuttings discharged from two drilling rigs near Sable Island. The two drill sites studied provided substantially different physical and oceanographic regimes. The Mobile West Venture C-62 site was located in about 16 m of water along the south side of the eastern bar of Sable Island where bottom sediments are well mixed by wind and wave action. The Shell South Des Barres O-76 site was located about 19 km north of the middle of Sable Island in approximately 70 m of water. During the time required to drill the well (summer and fall), the bottom sediments were not influenced to a significant degree by wave action. The limited influence of the waves on the sediments at South Des Barres made it an excellent location for fulfilling the secondary purpose of this study; namely, to study the dispersal of oiled cuttings by ocean currents. Although different commercial oil-base muds were used at each well (Technifluids "Biovert" System at West Venture C-62; Bariod "Environmul" at South Des Barres O-76), the same base oil (Conoco ODC) was used.

Samples were collected at both sites along eight radial lines. At West Venture, sediment grab samples were taken at distances of approximately 200 m, 500 m and 1000 m whereas at South Des Barres, the distances were 200 m, 800 m and 1500 m away from the wellhead. Reference samples were taken approximately 3 km away from the wellhead in the expected "upcurrent" direction of both locations. Total aliphatic hydrocarbons were used to trace the presence of base oil from the oiled cuttings.

At the West Venture site, hydrocarbon concentrations were observed to drop off to a level ten times above background at approximately 200 m from the wellsite. At South Des Barres, aliphatic hydrocarbon levels dropped to ten times above background at distances ranging from about 200 m to 1500 m from the wellhead. Core samples taken at the West Venture site indicate that oil concentrations decreased with depth along the core suggesting that some of the oil discharged with the cuttings may have floated to the top of the cuttings pile. The concentrations of Conoco oil in areas where cuttings had been discharged decreased by about two orders of magnitude after drilling ceased; sediment transport and the dispersal processes together with "weeping" of the oil fraction probably were responsible for the decrease.

Data in the report provide information on the weathering of Conoco oil and the post-depositional dispersal of cuttings and associated oil.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This study provides good information about the fate of oil-base mud cuttings in two depositional environments. It will form an excellent comparison with the results of a companion ESRF study being conducted in Beaufort Sea at the Minuk and Kaubvik drill sites by Arctic Laboratories Limited.

BEMP PROJECT OVERVIEW NO. 20-2

TITLE:	Environmental design criteria - Beaufort Sea
PRINCIPAL INVESTIGATORS:	D. Thomas, J. Hoff, J. MacDonald
AFFILIATION:	Arctic Laboratories Limited; ESL Environmental Sciences Limited
FUNDING SOURCE:	NOGAP
EXPECTED COMPLETION DATE:	March 31, 1986
RELEVANT BEMP HYPOTHESIS NUMBER(S):	20

BRIEF PROJECT DESCRIPTION

The purpose of this study is to focus monitoring priorities on the discharges related to offshore drilling containing contaminants of greatest environmental concern and on areas of greatest activity in the Beaufort Sea. The contaminants of concern have been identified on the basis of compound toxicities and usage rates. The emphasis of the study is on sediment parameter monitoring and setting sample number requirements for studies designed to detect environmental impact. A concept for "environmental detection limit" based on natural variability is being tested as an approach to monitoring of point source discharges.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This study will provide useful historical information about the input of various contaminants associated with offshore oil exploration (including hydrocarbons) into the Beaufort Sea. It will also permit "mass balance" type calculations to be made so as to put the input of oil from oil-base muds into a local and regional scale perspective.

BEMP PROJECT OVERVIEW NO. 20-3

TITLE:	Oil-based drilling muds: off structure monitoring - Beaufort Sea. Minuk I-53 and Kaubvik I-43
PRINCIPAL INVESTIGATORS:	P. Erickson, B. Fowler, D. Thomas
AFFILIATION:	Arctic Laboratories Limited
FUNDING SOURCE:	Environmental Studies Revolving Funds (ESRF)
EXPECTED COMPLETION DATE:	Fall 1987
RELEVANT BEMP HYPOTHESIS NUMBER(S):	20

BRIEF PROJECT DESCRIPTION

The purpose of this study is to monitor the distribution of base oil hydrocarbon concentrations in the vicinity of the two well sites in the Beaufort Sea (Minuk I-53 and Kaubvik I-43) and to determine the areal extent of discharged cuttings at the sites. The sampling programme calls for pre-drilling (background) and two post-drilling assessments of the areal distribution of base oil. To date only the background sampling has been completed. In addition to routine collection of sediments around the drill sites, the sampling programme includes collection of current, temperature and salinity near both sites during cuttings discharge and deployment of sediment traps at both locations during cuttings discharge. This additional oceanographic information will be essential in the interpretation of the chemical results.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

The results of this study will provide information about the fate of oiled cuttings in the Beaufort Sea waters. Information about the accumulation of the cuttings and their subsequent dispersal and redistribution in the benthic environment will be essential in assessing the possible effects of this discharge on populations of fish, birds and mammals in the Beaufort Sea.

BEMP PROJECT OVERVIEW NO.20-4

TITLE:	Oxygen demand of oiled drill cuttings
PRINCIPAL INVESTIGATORS:	M. Hutcheson, R. Odense
AFFILIATION:	Seakem Oceanography Limited
FUNDING SOURCE:	NOGAP
EXPECTED COMPLETION DATE:	Complete
RELEVANT BEMP HYPOTHESIS NUMBER(S):	20

BRIEF PROJECT DESCRIPTION

The purpose of this study was to determine the oxygen demand of oiled cuttings layered on the sea floor. The cuttings used for the study were from the Shell Alma F-67 well drilled on the Scotian Shelf in 1984. The total oil content of the cuttings was 8.4% and the base oil for the drilling fluid was Conoco mineral oil. Sub-objectives of the study were (1) to evaluate the influence of underlying substrate type and cuttings thickness on the oxygen demand of the cuttings; (2) to observe the change in redox potential of cuttings and sediments covered by seawater; and (3) to compare the pore water metal concentrations at the start and end of the 30-day flow-through experiments.

The main results of the experiments were as follows:

(1) natural oxygen consumption rates ranges from 0 - 4 mL O_2 $m^{-2}h^{-1}$ (fine sediment) and 1 - 7 mL O_2 $m^{-2}h^{-1}$ (coarse sediment);

(2) oiled cuttings layered over the natural sediments resulted in an increase in sediment oxygen consumption rate to as much as 18-fold above controls. Rates ranged from 0 - 19.2 mL O_2 $m^{-2}h^{-1}$;

(3) fifteen to thirty days are required for differences between experimental treatments to become evident;

(4) maximum increase of oxygen demand occurred with a 2.5 mm thick cuttings layer. The rate of oxygen demand tended to drop off slightly with thicker layers;

(5) the oxygen demand of cuttings layered over natural sediments can be predicted (approximately) by the following equations validated at about 1°C for cuttings thicknesses up to 15 mm over 30 days.

For Fine Sediments

$$O_2 = 3.68 - 0.27 \text{ (day)} - 1.60 \log_{10} (\text{thickness} + 0.05)$$

For Coarse Sediments

$$O_2 = 2.25 - 0.28 \text{ (day)} - 2.26 \log_{10} (\text{thickness} + 0.05)$$

(6) the redox potential through the cuttings and underlying sediments remained positive in all treatments over 30 days although some Eh profile changes were observed in the $\geq$ 2.5 mm cuttings treatments; and

(7) pore water concentrations of copper increased approximately 4-fold during the experiment under 15 mm of cuttings layered over fine sediments; zinc concentrations decreased similarly whereas mercury, cadmium and lead concentrations did not change.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This study will provide the data needed to evaluate Link 2 of Hypothesis 20; namely, that the accumulation of cuttings in benthic habitats will lead to elevated hydrocarbon concentrations and reduced oxygen concentrations. In addition, the relationship between cuttings thickness and oxygen demand will be useful in assessing the potential impact of the accumulation of oiled cuttings in Arctic benthic environments as a function of various disposal strategies and natural dispersal processes.

BEMP PROJECT OVERVIEW NO. 20-5

TITLE:	Long-term potential for leaching of oil-contaminated cuttings from the use of oil-base muds in the Arctic
PRINCIPAL INVESTIGATORS:	M. Yunker
AFFILIATION:	Dobrocky Seatech Ltd.
FUNDING SOURCE:	NOGAP
EXPECTED COMPLETION DATE:	The draft report is expected in April 1986
RELEVANT BEMP HYPOTHESIS NUMBER(S):	20

BRIEF PROJECT DESCRIPTION

A laboratory study has been designed to determine the rate and duration of release of oil and oil fractions from contaminated arctic drill cuttings. The potential formation and physical characteristics of a surface crust on the cuttings pile is also being documented.

Experimental conditions approximate physical and chemical shallow water Beaufort Sea characteristics. Water temperatures and maintained below 5°C and energy regimes of the experimental water tables simulate a shallow water (10-12 m) protected embayment (static) and a high energy embayment (wave generation tank). Uncleaned drill cuttings from the ADGO well have been allowed to settle in a uniform plane. The cuttings contaminated with CONOCO ODC oil (1% aromatic) will be monitored over a period of three months.

Samples are being taken of the cuttings and of the water column for total oil analysis by IR with additional selected GC analysis. The crustal formation and rate of hardening of the cuttings pile is being measured by penetrometer.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

Information provided by this study will be useful in evaluating the basal Link 1 for hypothesis 20. Both the rate and nature of the discharge anticipated from oil-base mud contaminated cuttings must be defined to address adequately the strength of the remaining linkages and the validity of Hypothesis 20 itself.

BEMP PROJECT OVERVIEW NO. 20-6

TITLE:	Impact of oil-base drilling muds (OBM) discharges cuttings
PRINCIPAL INVESTIGATORS:	R.F. Addison, J.R. Payne
AFFILIATION:	DFO, Dartmouth (NS) and DFO, St. John's (Nfld.)
FUNDING SOURCE:	PERD
EXPECTED COMPLETION DATE:	Final Report December 1986
RELEVANT BEMP HYPOTHESIS NUMBER(S):	20

BRIEF PROJECT DESCRIPTION

The purpose of this experimental study is to: 1) evaluate the sublethal and long-term effects of OBM discharges on potentially sensitive marine species; and 2) to determine the potential for tainting of commercial species caught in the vicinity of wells using OBM.

In a laboratory setting a range of cuttings with differing aromatic content (0-25%) will be used as a substrate in sublethal and long-term toxicity tests. The induction of hepatic mixed function oxidase (MFO) will be used as the sensitive indicator for the target species. These monitoring organisms will include American plaice or winter flounder and shorthorn sculpin.

Two exposure series will be run. The first 10-day exposure will establish the dose-response relationship between OBM cutting exposure (= aromatic HC exposure) and the induction of the MFO response. These results will be combined with analytical monitoring data to define a "no-effect" radius from the well.

The second exposure series will assess the effects of a lengthier period of exposure (30 days) on the induction of the MFO system. The potential for tainting will rely on the testing of the (30-day) plaice flesh for which liver MFO results will also be available. Additional studies will also expose the sessile mollusc (Mytilus sp.) to the 30-days OBM exposure. The flesh of both the fish and mollusc will then be tested by "an appropriate food organization".

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This study will provide useful information to determine the viability of Links 1, 2, 4, 6a and 9a of Hypothesis 20. It will also allow for the evaluation of a socio-economic facet to this hypothesis.

BEMP PROJECT OVERVIEW NO. 20-7

TITLE:	Acute and sublethal toxicity of oil-base drilling fluids, base oils and cuttings on marine and freshwater vertebrates and invertebrates
PRINCIPAL INVESTIGATORS:	J. Osborne
AFFILIATION:	Environment Canada, EPS, St. John's
FUNDING SOURCE:	NOGAP
EXPECTED COMPLETION DATE:	Final Report April 30, 1986
RELEVANT BEMP HYPOTHESIS NUMBER(S):	20

BRIEF PROJECT DESCRIPTION

The purpose of this study is to evaluate the acute lethal toxicity and the sublethal toxicity of base oils, of drilling fluids released from cuttings and of oil contaminated cuttings from three arctic wells (ADGO, Minuk, Nipterk). The study has two main components.

1. To determine the acute toxicity of base oils and decanted drilling fluids on selected freshwater and marine fish.

   The acute lethal toxicity will be measured as median lethal time (LT50) with 100% water-soluble fractions of base-oil and of fluid released by cuttings. All testing will be in accordance with the 1985 EPS procedure (Laboratory Procedure for Determining the Acute Lethality of Water-Soluble Fraction of Mineral Oil to Rainbow Trout).

   The acute toxicity of the base oil used at the Minuk well has been assessed using Salmo gairdneri. The LT50 of the drilling fluids released by the cuttings from ADGO and Nipterk have also been completed for the freshwater trout (S. gairdneri) and the marine stickleback (Gasterosteus aculeatus).

2. The second series of tests has been designed to assess the chronic or sublethal effects of oil contaminated cuttings from the ADGO, Minuk and Nipterk wells. Macoma sp. (soft shell clam) and Echinarachnius sp. (sand dollar) will be exposed to various ratios of silica sand and cuttings over a period of 20 days or more.

   In addition to routine behavioural observations of surface preference, burrowing and avoidance reactions, surface oil samples will be collected and analysed. Records will also be kept of the presence and duration of surface oil sheens.

   Additional sticklebacks will be exposed to the Nipterk sediment bioassay and provided to DFO, St. John's, for MFO investigation. Results of an earlier sediment bioassay test of the sublethal toxicity of Nipterk cuttings was conducted by EPS on behalf of DIAND. Results of this work will be intergrated into the NOGAP study for final publication. Macoma sp. and Echinarachnius sp. tissues from this study have been provided to DFO, St. John's for body burden analysis.

RELATIONSHIP AND RELEVANCE TO THE BEAUFORT ENVIRONMENTAL MONITORING PROJECT

This study will provide information on Link 3 of Hypothesis 20 which states that a reduced abundance of benthic fauna will result from the discharge of oil contaminated cuttings.

Both the effects related to acute and sublethal toxicity will be evaluated, thus yielding a more realistic assessment of the impacts of the marine disposal of oil contaminated cuttings on the benthos.